HOUSE DOCUMENT . . . . No. 500.

REPORT

OF THE

MASSACHUSETTS STATE BOARD OF HEALTH

UPON A

METROPOLITAN WATER SUPPLY.

FEBRUARY, 1895.

BOSTON:
WRIGHT & POTTER PRINTING CO., STATE PRINTERS,
18 POST OFFICE SQUARE.
1895.

[Chapter 459, Acts of 1893.]

AN ACT relative to procuring a Water Supply for the City of Boston and its Suburbs.

Be it enacted, etc., as follows:

SECTION 1. The state board of health is hereby authorized and directed to investigate, consider and report upon the question of a water supply for the city of Boston and its suburbs within a radius of ten miles from the state house, and for such other cities and towns as in its opinion should be included in connection therewith.

SECT. 2. The said board shall forthwith proceed to investigate and consider this subject, including all questions relating to the quantity of water to be obtained from available sources, its quality, the best methods of protecting the purity of the water, the construction, operation and maintenance of works for storing, conveying or purifying the water, the cost of the same, the damages to property, and all other matters pertaining to the subject.

SECT. 3. The said board shall have power to employ such engineering and other assistance and to incur such expenses as may be necessary for carrying out the provisions of this act.

SECT. 4. The said board shall report fully with plans and estimates to the legislature on or before the first Wednesday in January in the year eighteen hundred and ninety-five, and shall append to its report drafts of bills intended to accomplish the recommendations of the board.

SECT. 5. The total amount of money which shall be expended out of the treasury of the Commonwealth in carrying out the provisions of this act shall not exceed forty thousand dollars. The Commonwealth shall be reimbursed for the amount expended by the cities and towns which are to receive the benefit of the system recommended in the report, in proportion to the population of each.

SECT. 6. Before incurring any expense the board shall from time to time estimate the amounts required and shall submit the same to the governor and council for their approval, and no expense shall be incurred beyond the amount so estimated and approved.

SECT. 7. This act shall take effect upon its passage. [*Approved June 9, 1893.*

[Chapter 4, Resolves of 1895.]

RESOLVE extending the Time for the Report of the State Board of Health upon the Subject of a Metropolitan Water Supply, and providing for the Continuance of the Investigation relative thereto.

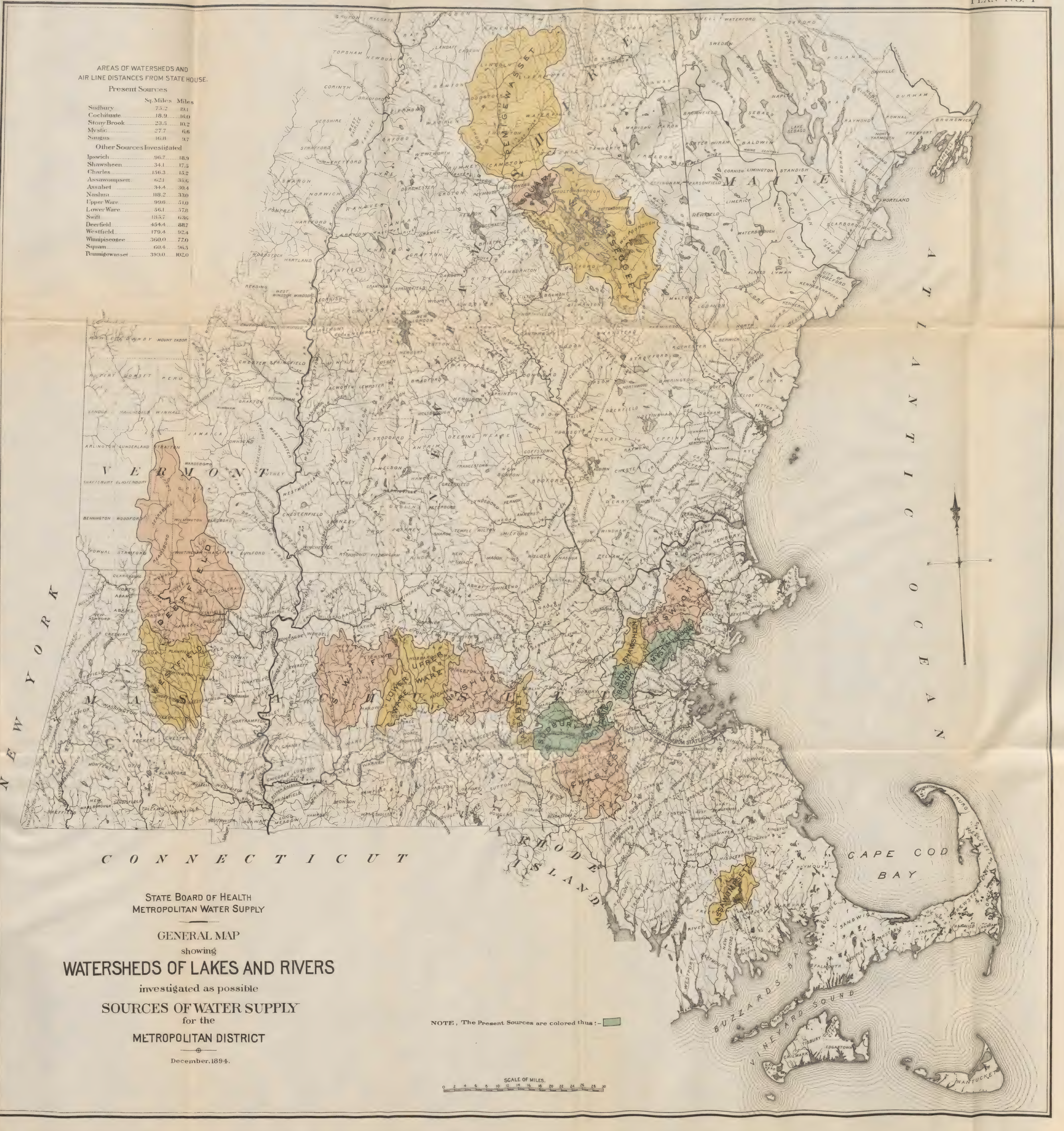
Resolved, That the time allowed for the filing of the report of the state board of health, required by chapter four hundred and fifty-nine of the acts

of the year eighteen hundred and ninety-three, relative to procuring a water supply for the city of Boston and its suburbs, is hereby extended until the first Wednesday in February in the present year; and that there be allowed and paid out of the treasury of the Commonwealth a sum not exceeding two thousand five hundred dollars, to be expended under the direction of the said board in continuing and completing the investigations, plans and report relative thereto, said amount being in addition to the forty thousand dollars provided for in said act, and to be reimbursed to the Commonwealth in the manner therein provided. [*Approved February 12, 1895.*

TABLE OF CONTENTS.

List of Maps, Plans and Diagrams.

List of Maps, Plans and Diagrams.


AREAS OF WATERSHEDS AND
AIR LINE DISTANCES FROM STATE HOUSE.
Present Sources
Sq. Miles Miles
Sudbury 75.2 19.4
Cochituate 18.9 16.0
Stony Brook 23.5 10.2
Mystic 27.7 6.6
Saugus 16.8 9.7
Other Sources Investigated
Ipswich 96.7 18.9
Shawsheen 34.1 17.5
Charles 156.3 15.2
Assawompsett 62.1 35.6
Assabet 34.4 30.4
Nashua 118.2 33.0
Upper Ware 99.6 51.0
Lower Ware 56.1 57.8
Swift 185.7 63.6
Deerfield 454.4 88.7
Westfield 179.4 92.4
Winnipiseogee 360.0 77.0
Squam 60.4 96.5
Pemmigewasset 399.0 102.0
STATE BOARD OF HEALTH
METROPOLITAN WATER SUPPLY
GENERAL MAP
showing
WATERSHEDS OF LAKES AND RIVERS
investigated as possible
SOURCES OF WATER SUPPLY
for the
METROPOLITAN DISTRICT
December, 1894.
NOTE, The Present Sources are colored thus:-
SCALE OF MILES.
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
NEW YORK
VERMONT
MAINE
CONNECTICUT
RHODE ISLAND
ATLANTIC OCEAN
CAPE COD BAY
BUZZARDS BAY
VINEYARD SOUND
NANTUCKET

Commonwealth of Massachusetts.

REPORT OF THE STATE BOARD OF HEALTH

UPON A

METROPOLITAN WATER SUPPLY.

To the Honorable the Senate and House of Representatives of the Commonwealth in General Court assembled.

The State Board of Health, acting under the authority of chapter 459 of the Acts of 1893, has investigated and considered the question of a water supply for the city of Boston and its suburbs within a radius of ten miles from the State House, and for such other cities and towns as, in its opinion, should be added thereto; and has also made the additional investigations set forth in the second section of the same act, and now desires to submit the following report: —

The act under which the Board has conducted this inquiry apparently provides for the same general treatment of the question of water supply as was adopted by the General Court of 1887 for the creation of a sewerage system for a somewhat smaller district. Substantially all the arguments that were urged by this Board for the metropolitan sewerage system, which, built in accordance with our recommendations, is now nearly completed, may be used with even greater force in aid of any well-devised plan for giving to a still larger district a sufficient supply of the best water attainable.

F. P. Stearns, C.E., chief engineer of the Board, has prepared the very full and accurate statement of the present and future resources of water available for this metropolitan district, together with all necessary details as to the structures at the great reservoir, the aqueduct leading from it, the new pipe lines and pumping stations, within the district; and, in addition to the information already in possession of the Board, has been able to state the results of many new inquiries undertaken for the purposes of this report. The financial

aspects of the problem are also treated by him in an instructive manner.

J. P. Davis, C.E., who has been for a series of years entirely familiar with all the great municipal works for water and sewerage of the metropolitan district, has made a careful examination of the work of our engineer, and finds it to be well considered and trustworthy. Mr. Davis was for many years city engineer of Boston, and in this capacity designed and had charge of the construction of the works for taking water from the Sudbury River. He has also been consulting engineer to the Aqueduct Commission of the city of New York, and was one of the experts consulted as to the proposed Quaker Bridge Dam.

Dexter Brackett, C.E., has embodied in two appendices the results of observations and studies to which he has devoted many years.

Another appendix, numbered 3, contains a description by Desmond FitzGerald, C.E., of plans for the draining of swamps, which are now under consideration for the improvement of the Sudbury water-shed.

Dr. Drown's paper upon the influence exercised by organic matter in the soil of reservoirs upon the water stored therein has so much that bears upon the recommendations of this report that we again publish it in Appendix 4.

All the special information that may be found necessary to explain or support the compressed conclusions of our own report will be supplied by the valuable reports of the eminent authorities above enumerated.

The most familiar experience of this part of the world, at least in the matter of its water supplies, has been the failure of sources originally supposed to be abundant to properly meet the wants of their respective communities for any considerable length of time. The plans of the city of Boston, beginning with its first scheme for a general water supply in the year 1825, have proved no exception to this rule, and yet this city has had the services of the ablest men of their day.

The reason for this constant disappointment is easily discovered. The quantity of water which the householder of to-day demands for the conveniences as well as for the necessities of his daily life has increased beyond all expectation. If this enlarged quantity can be secured without undue delay and without such injury as may easily

be made whole, it is evidently for the general welfare that such provision should be made: for it seems to us reasonable to claim that no small share in the improved and still improving state of the public health may be traced to the measures now adopted for the protection of the purity of waters and to the greater cleanliness of person, clothing and all surroundings which inevitably result from a practically unlimited freedom in the use of water. It is essential, then, to determine, if possible, the amount of water needed at the present day, with such forecast as to future requirements as can be safely made.

It is, of course, true that a comparatively small amount of pure water would meet all the demands for drinking and cooking, and that a water of inferior quality would answer for other domestic purposes as well as for all municipal requirements and the demands of manufactures; but no satisfactory arrangement has as yet been made by which two kinds of water can be economically and safely distributed through the streets and buildings of cities and towns.

It was discovered by this Board, some years since, that no inconsiderable portion of the cases of typhoid fever found in certain manufacturing towns in this State was the result of the careless drinking of a dangerous water, which is used in the mills for mechanical purposes only, is understood to be dangerous and is distinctly so marked; but this inferior water was still used by the operatives, because it was sometimes cooler, was tasteless, and generally more accessible.

The Board has hoped that it might be possible to devise some plan by which the very limited amount of quite pure water really needed in our houses might be secured and distributed; but no satisfactory method has as yet suggested itself, nor with the present outlook for an abundant supply of very good water does such a plan seem to be an urgent need either on grounds of health or economy.

The average daily consumption of water in the metropolitan dis trict for the year 1894 was 79,046,000 gallons, the average daily capacity of the sources now in existence for the supply of this district was only 83,700,000 gallons; that is to say, the average daily supply is only 4,654,000 gallons in excess of the actual needs. Though some of the sources of supply to the district are capable of yielding larger quantities of water than are at present furnished (as will be shown in detail in the accompanying report of our engineer), we are satisfied that even a very thorough development of all these

sources will barely carry the district safely through a year of unusual drought, should such a season occur before the date at which the works, hereafter to be described, can be put in condition to increase the supply; and this would be true even though the cities or towns which might find themselves possessed of a surplus supply could transfer it to their neighbor in want.

The population of this metropolitan district was, by the United States census of 1890, 844,814. Estimates which have been carefully made, and with a due regard to the diminution in rate of increase by reason of the depression in business, place the population for the year 1895 at 984,301. The water works of the city of Boston now supply nearly 75 per cent. of all the water used in the metropolitan district. The daily average consumption of those cities and towns receiving water from the Boston works was 99 gallons in 1893, and the average for the entire district now under consideration was, for the same year, 83 gallons. It seems to be generally true that the nearer we approach the centres of population the greater becomes the use of water; and, with the inevitable growth of Boston and its suburbs, it does not appear to us wise to calculate upon a requirement per inhabitant of less than 100 gallons for the long period of years for which we seek a supply.

We have not deemed it necessary or advisable to busy ourselves with the insoluble problem of the probable future increase of population in and about Boston. We have assumed that the growth will go on as it has gone on during the last quarter of a century; and for a population determined by such principles we have made provision.

While every effort has been made to reconcile the views of the local authorities with our own as to their respective requirements both in regard to quantity and quality of water needed and their capacity to meet such demands, the Board has in several cases arrived at results quite different from those held by these authorities. It is assumed that no portion of this large and intimately associated community will accept for any length of time a water inferior to that enjoyed by their neighbors, either in healthful qualities or attractive appearance and odor; and it will not be profitable as a municipal investment to offer the stranger seeking a new home anything so essential to his health and comfort as water is, that shall be decidedly poorer than the article distributed on the other side of the town's borders.

It has, therefore, been assumed by us that the various communities under consideration will take, sooner or later, the better water, pro-

vided that the cost of taking it is not in excess or greatly in excess of that of an existing and inferior supply.

It will also be found to be true, we think, that a very large amount of the best water can be provided for the district at a price per head far below that at which any municipality within the district, with the exception probably of Brookline, Newton and Waltham, can supply a water of anything like an equal quality. Moreover, in our opinion, the most favored locality in this region has no prospect of obtaining beyond the next twenty or twenty-five years any source of supply that can be favorably compared, either on grounds of health or economy, with the source to be later described. It is by no means certain that Waltham, even with its present abundant and good supply, can continue to depend through a series of years upon water filtered uninterruptedly in ever-increasing quantities from a river more or less polluted.

Of the communities composing the metropolitan district, those using 80 per cent. of the full amount of water will need the metropolitan supply nearly as soon as it can be furnished. It is probably possible for those using 10 per cent. of the full amount to extend their works so that they may give them a supply for twenty or twenty-five years, and the remaining 10 per cent. will need the metropolitan supply within a shorter time.

The works of distribution have been so designed that the first cost will be increased as little as practicable, and that they may be in condition to supply these communities when they shall need the water, by additions to the works first constructed; but some expense must necessarily be incurred at first, on account of the prospective use by these communities.

For the purpose of determining which cities and towns should be included in the district to be formed, a careful review has been undertaken of all the facts within our reach which have a bearing upon this question, — facts which will be found duly stated in the subjoined report of the engineer, Mr. Stearns; and we accordingly recommend that the cities of Boston, Cambridge, Chelsea, Everett, Lynn, Malden, Medford, Newton, Quincy, Somerville, Waltham and Woburn, and the towns of Arlington, Belmont, Brookline, Hyde Park, Lexington, Melrose, Milton, Nahant, Revere, Saugus, Stoneham, Swampscott, Wakefield, Watertown, Winchester and Winthrop, twenty-eight cities and towns, containing, in 1890, 848,012 inhabitants, constitute the metropolitan water district.

Inasmuch as the cities of Cambridge, Lynn, Newton, Waltham and Woburn, and the towns of Brookline, Lexington, Nahant, Saugus, Swampscott and Winchester, together containing, in 1890, 210,252 inhabitants, believe that they have a sufficient supply for some years to come, we do not recommend that they be provided with water from the metropolitan supply until they formally express their wish for it. These municipalities contained about one-fourth of all the people living in the proposed district in the year 1890. We have no hesitation in recording our own belief that the period at which this supply will be demanded by them is much nearer than they now anticipate; but their participation in the scheme is not essential to the success of the undertaking, nor will their absence render the immediate procuring of a new water supply any the less necessary.

After a thorough revision of all the sources of water which have been suggested or which we could discover, we selected three which seemed worthy of critical examination, — Lake Winnipiseogee in New Hampshire, the Merrimack River above Lowell and the Nashua River above Clinton.

Lake Winnipiseogee has for many years been held to be the ideal of all that was needed in the way of a perfect source of pure water, and it is capable of furnishing an abundant and excellent supply. The clear depths of its waters and the apparent freedom from pollution along its shores, unlike many of the artificial reservoirs hitherto constructed, have created so strong a popular belief in its necessary superiority to anything artificial that it may not be out of place to direct attention for a moment to some of the defects to be found even here. The permanent population on the territory draining to the lake is not large, — 35 persons per square mile; but the attractive shores have become the favorite summer camping-ground of thousands, and the amount of the most serious forms of pollution directly entering the water of the lake must be large and ever-growing. Even though the State of New Hampshire might allow a certain amount of water to be taken from this lake for domestic water supply within her own limits, it is not probable that she would consent to the withdrawal of amounts of water so large as to injure her own manufacturing industries, or to give to the people of another State any authority to interfere by police regulations with the unhampered enjoyment by her own citizens of her beautiful pleasure-grounds.

The expense, however, of constructing a conduit over the shortest and best route which it has been possible to discover, and for distributing this water through the district, amounts to $34,000,000. This large sum does not include the cost of the damages inflicted by the diversion of water and charges incident thereto; and we are confident that the water thus obtained would have no greater value than supplies which can be obtained at much smaller cost within the limits of this State and protected by our own laws.

Examinations have also been made with the view of taking the water of the Merrimack River above Lowell, subjecting it to efficient filtration and bringing it down into the metropolitan district. The quantity of water that could be obtained in this way and for this purpose is unlimited; and, if there were no way of obtaining a better supply of water and one which was above suspicion, it would be practicable to introduce water from that source at a cost somewhat less than from any other source considered.

The estimated cost of filtering and conveying this water to the metropolitan district is $17,500,000; but in the opinion of the Board it will be better to pay 10 per cent. more for a supply from a source that has not been polluted. The experiments carried on by this Board for a succession of years at an experiment station in Lawrence under the immediate direction of H. F. Mills, C.E., a member of this Board, and the filter constructed in connection with the water works of that city, have shown that waters as polluted as those of the Merrimack can be effectually filtered and rendered safe for domestic use; but it is also true that filtering areas require continuous care on the part of well-trained attendants, and that, in a few instances at least, inefficient administration or inherent defects of construction have allowed disease germs to pass through filters which were assumed, by good authority, to be a sufficient protection.

We are the more easily led to reject the filtered waters of the polluted Merrimack because we have found an entirely satisfactory water in the South Branch of the Nashua River above the city of Clinton. We find that the conduit of the Boston water works was built of much larger capacity than was needed for the conveyance of the amount of water to be derived from the Sudbury River, being capable of taking 50,000,000 gallons a day more than is at present supplied to it. The territory from which an additional supply for this district may be sought is thus moved out to the westerly end

of this conduit, or to the westerly end of the valley and reservoir connected with this conduit.

The first source of considerable size found to the west of this point is the above-named South Branch of the Nashua, which, at the city of Clinton, has a water-shed of 118.23 square miles, consisting of a sparsely settled district containing but 69 persons to the square mile. The southerly and easterly slopes of Wachusett Mountain which bound this territory to the north and west are not well adapted to agriculture, and offer few inducements to the establishment of manufactures. In this section the rate of increase of population has been very slight, and the distance from centres of population is such that no more rapid rate of growth can be expected in the future.

In this river, a short distance above the Lancaster Mills in Clinton, a dam can be built which will raise the water 107 feet above the surface of the existing mill-pond, and flowing to the average depth of 46 feet an area of 6½ square miles, with its high-water mark 385 feet above the level of high tide in Boston harbor. This reservoir will have a capacity of 63,000,000,000 gallons, and the territory draining into it will supply, in a series of very dry years, 111,000,000 gallons of water daily, which, with the 62,000,000 gallons obtainable from the Sudbury and Cochituate water-sheds, will make the total capacity of the combined sources 173,000,000 gallons, which is double the capacity of all the sources now utilized by the metropolitan district.

The reservoir can be connected with the new Reservoir No. 5 now constructing by the city of Boston in the Sudbury River system. The connection would be made by an aqueduct a little less than 9 miles long, and an open channel about 3 miles long following the course of an existing brook. This aqueduct is designed to be built low enough to take water from the level of the present mill-pond in Clinton; so that, should it become necessary to increase the supply to the metropolitan district before the dam and reservoir are completed, the ordinary flow of the river could be brought down into the Sudbury system as soon as the aqueduct is built.

The very great merit of the plan now submitted is to be found in the fact that this extension of the chain of the metropolitan water supplies to the valley of the Nashua will settle forever the future water policy of the district, for a comparatively inexpensive conduit can be constructed through to the valley of the Ware River, and

xvi


PROFILE
PROPOSED NASHUA RIVER RESERVOIR TO SPOT POND.
PROPOSED NASHUA RIVER RESERVOIR
TUNNEL
PROPOSED AQUEDUCT
OPEN CHANNEL
RESERVOIR NO. 5 B.W.W.
PROPOSED FUTURE AQUEDUCT
WESTON
WALTHAM
BELMONT
ARLINGTON
MEDFORD
PIPE LINE
SPOT POND
STATE BOARD OF HEALTH
METROPOLITAN WATER SUPPLY.
MAP
SHOWING
PRESENT AND PROPOSED WORKS
FOR SUPPLYING WATER FROM THE
NASHUA, SUDBURY AND COCHITUATE
WATERSHEDS
TO THE
METROPOLITAN DISTRICT.
December, 1894.
NASHUA
SUDBURY
COCHITUATE
PRESENT SUDBURY AQUEDUCT
PRESENT COCHITUATE AQUEDUCT
PROPOSED FUTURE AQUEDUCT
10 MILES FROM STATE HOUSE
SCALE
EXPLANATION
Existing Reservoirs are shown thus:
Proposed Nashua River Reservoir "
Areas of Watersheds
Cochituate 18.87 Square Miles
Sudbury 75.20 " "
Nashua 118.23 " "
Total 212.30 " "

beyond the Ware River lies the valley of the Swift; and, in a future so far distant that we do not venture to give a date to it, are portions of the Westfield and Deerfield rivers, capable, when united, of furnishing a supply of the best water for a municipality larger than any now found in the world.

The expense of this great scheme is comparatively moderate, because the water-sheds in question are sparsely settled, lie among the higher regions of the State, and are not likely to become the seat of manufacturing industries. Moreover, all these streams can be brought down by their own natural flow from appropriate reservoirs to the existing distributing basins in the metropolitan district.

The water in the South Branch of the Nashua River is at present of good quality, and, with the small population upon its drainage area, it will not be difficult to protect it from impurities in the future; but, in the opinion of the Board, the large reservoir to be constructed will serve as a means of very much improving the quality of the water; its area and depth are so great that it will contain, at nearly all stages at which it is proposed to hold the water, a full year's supply when double the quantity now used in the metropolitan district is drawn from it and the Sudbury and Cochituate areas. During the long period through which water remains in this reservoir a bleaching and purifying process will go on, which will probably cause the death of all the disease germs which may be turned into it from contributing streams, and the water thus become more agreeable to the sight and taste, and be, in fact, more wholesome than the present water from any of its contributing streams. In order that this may be the case, the Board has thought best to increase the depth of the reservoir by raising the dam, and to remove from its area the vegetable matter and soil which may cover it, and thus expend about $4,000,000 in rendering the water of the best quality practicable.

So many advantages are offered by larger storage reservoirs, as compared with the smaller basins, which local geographical peculiarities have compelled the metropolitan district to build hitherto, that it has seemed advisable to us to urge the completest possible preparation of this new reservoir.

After this new water has been brought into the Sudbury system, it will pass down into Chestnut Hill Reservoir, where it will for the first time require to be pumped to an elevation of 30 feet, sufficient to give an additional head to the Boston low-service system and to

carry over to Spot Pond the supply needed for the northerly portion of the metropolitan district. In our estimates of cost a sum of money has been set aside for the improvement of Spot Pond, principally for removing its shallow flowage, and we believe it will then be a valuable distributing reservoir and restored to its normal height.

It is estimated that no other conduit will be required in addition to the present one from Sudbury River to Chestnut Hill Reservoir for ten or more years; but before the end of this period it will be necessary to build an additional conduit, extending from Reservoir No. 5 of the Boston water works to a point in the town of Weston not far from the Charles River, at such a height that the water may be conveyed in pipes to Spot Pond, and be distributed through the low-service system in the metropolitan district by gravity. This aqueduct will be $13\frac{1}{2}$ miles long, and is designed to convey 250,000,000 gallons of water per day.

Spot Pond is selected for a general distributing reservoir in order that the low-service district may have a pressure 30 or 40 feet greater than would be supplied by Chestnut Hill Reservoir; this increased pressure is rendered necessary in order to include large areas in the district which would be inadequately served by the lower reservoir and by the custom of constructing very high buildings upon the low-lying territory.

The method of distributing the water over the metropolitan district is given in detail in the report of the chief engineer; it is designed to supply to each community within the district a sufficient quantity of water for its use at a pressure sufficient for all requirements within its territory, and it will be feasible to supply all the highest portions of the district more efficiently than at present from a much smaller number of stations and at a much diminished charge for annual maintenance.

In considering the plans for the proposed reservoir above the Lancaster Mills, we have been impressed by the very serious changes which will be produced in the towns of Boylston and West Boylston. It does not appear to us to be a very important objection to our plan that certain mill sites will be 80 feet beneath the surface of the basin, nor that the homes of many industrious people dependent upon these mills for their living will be also submerged, because all these can be paid for, and an equivalent will be given, — damages for which we have caused careful estimates to be made. But we have not deemed it to be within our province to decide upon a plan for making good

the many other losses that must of necessity fall upon these sorely diminished townships, — the burden of a town debt for which much of the available security has been taken away, the loss of a near market for the farmer upon the outskirts of the town, and the many other losses which will naturally suggest themselves. We can only state that we recognize the existence of these losses, that we believe some form of compensation should be granted, and that the benefit to the metropolitan district by reason of a pure water supply in abundant quantity will be so great that this district, which contains more than half the taxable property of the State, can afford to pay for all the injury inflicted; at the same time we must leave the suggestion, even, of the nature of the remedy, to the wisdom of your honorable body.

The total assessed valuation of West Boylston for 1894 was . .	$951,610
Assessed value of property to be taken, ...	557,730
The total assessed valuation of Boylston for 1894 was	429,435
Assessed value of property to be taken, ...	165,200

In preparing the estimates for the cost of the great work here sketched out, we have brought to our assistance the best expert aid, and believe that the works can be constructed within the estimates which have been liberally made with the usual allowance for contingencies.

It may also be of interest to you to know that, of the whole water-shed of the Nashua River above the city of Nashua in New Hampshire, at which place the Nashua enters the Merrimack, the proposed reservoir cuts off 22 per cent.; but, with the provision which is inserted in the draft of an act herewith submitted for allowing a stated quantity of water to be discharged into the mill-pond below the reservoir dam, the deprivation of water will not be so extensive as the proportion of reservoir water-shed to the whole water-shed of the Nashua would indicate.

The estimates of cost have been made by Mr. Stearns, the chief engineer of the Board. They have been made from carefully prepared designs, and are intended to be sufficient to include the full cost of the completed work.

The cost of the works necessary to supply all the communities of the metropolitan district for the next ten years with the main part of the works of sufficient capacity for a long future is estimated as follows: —

Reservoir on Nashua River, including the cost of land, buildings and water rights taken, the relocation of roads and railroads, the removal of all soil from the site of the reservoir, the construction of dams and dikes and all incidental expenses,	$9,105,000
Improvement of the water-shed of the Nashua River and of the Stony Brook branch of the Sudbury River by the diversion and purification of sewage and drainage of swamps,	513,000
Aqueduct from the Nashua River to the Sudbury water-shed and open channel from the end of the aqueduct to Reservoir No. 5,	2,265,000
Additional forty-eight-inch pipe from Dam No. 3 to Dam No. 1 and across the Rosemary valley,	78,800
Pumping stations, reservoirs and pipe systems for elevating and distributing water to all of the cities and towns in the metropolitan district, including the improvement of Spot Pond,	5,584,000
Damages for the diversion of water from the Nashua River and incidental damages not included above,	1,500,000
Total first cost of proposed works for supplying water to *all* of the cities and towns in the metropolitan district,	$19,045,800

The estimates of damages for the diversion of water from the Nashua River are believed by the Board to be ample to cover all reasonable demands, and are made large enough so that it is probable that some of the more important can be settled within the estimate without litigation.

It is not proposed in the driest year to lower the water in the reservoir more than sixty feet, and there will always be a great fall between the surface of the water in the reservoir and in the aqueduct leading from it. It is estimated that this fall may be utilized to furnish 1,000 horse-power by day and 500 horse-power by night for the first fifteen years, and nearly as much for the following years.

The estimated first cost of the proposed works for supplying water to all of the cities and towns in the metropolitan district is, as above stated,	$19,045,800
Within the next ten years, if the water is used by all of the cities and towns, there will be required an additional expenditure for an aqueduct from Reservoir No. 5 to Weston, and for main pipes and an aqueduct therefrom to the existing distributing system and to Spot Pond of	4,982,000
In the second ten years a further expenditure will be necessary for additional pipes from Weston and for improving a portion of the Sudbury River water-shed, not included in the first estimate, of	1,300,000
Total expenditure for full development of Nashua River source, and for a supply of 173,000,000 gallons of water per day distributed to all of the cities and towns in the metropolitan district,	$25,327,800

After these twenty years, should the growth of the district be as estimated, additions will have to be made by adding certain tributaries of the Assabet River, or by extending the works to the valley of the Ware River, either of which can be done at a comparatively small cost.

l
(
S

pl
12,

PLAN No. 3


STATE BOARD OF HEALTH
METROPOLITAN WATER SUPPLY.
MAP SHOWING WORKS
BY WHICH WATER MAY BE TAKEN FROM THE
ASSABET, WARE AND SWIFT RIVERS
TO SUPPLEMENT THE SUPPLY FROM THE
NASHUA, SUDBURY AND COCHITUATE
WATERSHEDS.
December, 1894.
EXPLANATION
Proposed Reservoirs are shown thus:
Areas of Watersheds
Assabet 34.41 Square Miles
Nashua 118.23 " "
Upper Ware 99.63 " "
Lower Ware 56.10 " "
Swift 185.66 " "
Total 494.03 " "
SWIFT
LOWER WARE
UPPER WARE
NASHUA
ASSABET
SUDBURY
PROPOSED TUNNEL FROM WARE RIVER
POSSIBLE TUNNEL LINE
FROM SWIFT RIVER
PROPOSED SWIFT RIVER RESERVOIR
PROPOSED NASHUA RIVER RESERVOIR
ALTERNATIVE LOCATION OF TUNNEL FROM WARE RIVER
Length 8.88 miles
PROPOSED TUNNEL FROM SWIFT AND WARE RIVERS
Length 27.66 miles
QUINEPOXET RIVER
Note
The profile between the 24th and 31st miles follows the channel of the Quinepoxet River which is much longer than the straight tunnel line between these points.
MUDDY BROOK
WARE RIVER
WHITEHALL BROOK
Boston W.W. base (Tide Marsh level)
WORCESTER
CLINTON
WEST BOYLSTON
PETERSHAM
HUBBARDSTON
BARRE
RUTLAND
HOLDEN
PRINCETON
GREENWICH
ENFIELD
PRESCOTT
GILBERTVILLE
NORTHBOROUGH
WESTBOROUGH
SHREWSBURY
BELCHERTOWN
PELHAM
SHUTESBURY
LEVERETT
FITCHBURG
GARDNER
ATHOL
ORANGE
MARLBOROUGH
SOUTHBOROUGH
HOPKINTON
HUDSON
BERLIN
BOLTON
STERLING
PAXTON
HARDWICK
OAKHAM
NEW BRAINTREE
NORTH BROOKFIELD
MILLERS FALLS
MILFORD
UPTON

The annual cost for interest, sinking fund and maintenance of the works for supplying the whole district when the works are first completed is estimated to be ninety-three cents per inhabitant, and the cost will decrease with the growth of population.

In conclusion, we desire to again call your attention to our profound conviction of the need of prompt action in entering upon works of construction which cannot for years be completed, and of which the absolute necessity will at an early day be forced upon this community; and we are confident that we have pointed out an economical as well as practicable means of securing one of the most essential conditions for healthy human life.

H. P. WALCOTT,
J. W. HASTINGS,
H. F. MILLS,
F. W. DRAPER,
G. C. TOBEY,
J. W. HULL,
C. H. PORTER,
State Board of Health.

Expenditures for Metropolitan Water Supply Investigations.

Appropriations made in 1893 and 1894,		$40,000 00
Expenditures to Feb. 1, 1895: —		
Salaries of engineers, experts and assistants,	$30,152 36	
Travelling expenses and subsistence of engineers,	3,229 33	
Laborers employed in making borings,	3,545 05	
Boring apparatus, repairs and materials,	1,818 90	
Digging test-pits,	254 30	
Printing,	50 32	
Stationery and drawing materials,	368 46	
Instruments and repairs,	149 73	
Books, maps and map mounting,	185 49	
Office fixtures and furniture,	43 55	
Small supplies and miscellaneous expenses,	195 25	39,992 74
Balance,		$7 26

An additional appropriation of $2,500, for continuing and completing the investigations, plans and report, became available Feb. 12, 1895.

AN ACT to provide for the building, maintenance and operation of a system of water supply for the metropolitan water district.

SECTION 1. The governor, by and with the consent of the council, shall appoint three men, inhabitants of the Commonwealth, who shall constitute a board to be known as the metropolitan water board, and who shall hold office, one for the term of five years, one for the term of four years, and one for the term of three years, from the first Monday in May in the year eighteen hundred and ninety-five; and in the year eighteen hundred and ninety-eight, and annually thereafter, the governor shall appoint, as aforesaid, one member of said board to hold office for the term of three years, beginning with the first Monday in May in the year of his appointment; and if any vacancy occurs in said board by resignation or otherwise the governor shall in like manner appoint a member for the residue of the term in which said vacancy occurs, and may, with the consent of the council, remove any member of the board. The chairman of the board shall receive a salary of $5,000 per year, and the other members a salary of $4,000 per year.

SECTION 2. Said board shall, as soon as may be after its appointment and annually thereafter on the first Monday of May, organize by the choice of one of its members as chairman, and may from time to time appoint an engineer, a secretary, and such other agents, officers, clerks and servants as it deems necessary to carry out the purposes of this act, and may employ counsel. It may determine the duties and compensation of such appointees, remove the same at pleasure and make all reasonable rules and regulations. On or before the first Wednesday in January in each year said board shall make report of its proceedings to the general court, together with a full statement of its receipts and disbursements, such report to be numbered as one of the series of public documents, and four thousand five hundred copies thereof shall be printed annually.

SECTION 3. The cities and towns for which said board shall provide a water supply are the cities of Boston, Cambridge, Chelsea, Everett, Lynn, Malden, Medford, Newton, Quincy, Somerville, Waltham and Woburn, and the towns of Arlington, Belmont, Brookline, Hyde Park, Lexington, Melrose, Milton, Nahant, Revere, Saugus, Stoneham, Swampscott, Wakefield, Watertown, Winchester and Winthrop, which cities and towns shall constitute the metropolitan water district: *provided, however*, that the said board shall not furnish a supply of water to the cities of Cambridge, Lynn, Newton, Waltham and Woburn, and the towns of Brookline, Lexington, Nahant, Saugus, Swampscott and Winchester until requested to do so by the city, or by the inhabitants of the town voting in town meeting, in case the water works are owned by the city or town, or by the water company, acting by its board of directors, in case the city or town is supplied with water by a water company; but this provision shall not be held to pre-

vent the said board from furnishing by agreement, from pipes located in or passing through any city or town, water for extinguishing fires, or to prevent a failure of the supply in said city or town in the case of accident or other emergency.

SECTION 4. The said board shall construct, maintain and operate a system of water supply for the benefit of the cities and towns before mentioned, which system shall be in substantial accordance with the plans reported and recommended by the state board of health in its report to the legislature of the year eighteen hundred and ninety-five; and for this purpose it may make all necessary contracts for the construction of the dams, reservoirs, aqueducts, pumping stations, main-pipe systems and other works required for or incidental to furnishing the aforesaid cities and towns with a supply of pure water and for improving and protecting the purity of the supply, or may, where deemed advisable, carry on such construction or work by day labor.

SECTION 5. Said board, acting in behalf and in the name of the Commonwealth, may take and hold by purchase or otherwise, as far as may be necessary or advisable in the opinion of said board to carry out the provisions of this act, and convey to, into or through said metropolitan district, all or any part of the water, except as hereinafter provided, of the South Branch of the Nashua river at and above the dam at the Lancaster Mills in the town of Clinton, also the water of Sandy Pond, so-called, in said town of Clinton, and the waters which may flow into and from said river and pond, any water rights in or upon said river and pond at or above the points hereinbefore mentioned in said town of Clinton, and any lands in fee or rights and easements in land, and any existing reservoirs, ponds, aqueducts, pipes, pumping stations, or other works now owned or controlled by any city or cities, town or towns or water company in the metropolitan district; and the said board may also contract with any city, town or water company for pumping or conveying through pipes any part of the water furnished by it for the supply of the metropolitan district. When any lands, water courses, rights of way or easements, or any reservoirs, ponds, aqueducts, pipes, pumping stations or other works are so taken or entered and used in any manner other than by purchase or agreement, said board shall, and in all cases may within thirty days of such taking or entering and using, cause to be recorded in the registry of deeds for the county or district in which such lands, water courses, rights of way or easements, or reservoirs, ponds, aqueducts, pipes, pumping stations or other works lie, a description of the same as certain as is required in a common conveyance of land, with a statement of the purpose for which the same is taken or entered and used, which description shall be signed by a majority of said board; and upon such record the fee of or easement in the lands, water courses, rights of way or easements, reservoirs, ponds, aqueducts, pipes, pumping stations or other works so taken or purchased

SECTION 9. Whenever said board shall dig up any road, street or way, as aforesaid, it shall, so far as practicable, restore the same to as good order and condition as the same was in when such digging commenced, and the Commonwealth shall at all times indemnify and save harmless the several cities and towns, within which such roads, streets or ways may be, against all damages which may be recovered against them respectively, and shall reimburse to them all expenses which they shall incur by reason of any defect and want of repair in any road, street or way, caused by the construction of any of said aqueducts, conduits or pipes, or by the maintaining and repairing of the same, provided that said board shall have due and reasonable notice of all claims for such damages or injury and opportunity to make a legal defence thereto.

SECTION 10. Said board may also alter or change the course or direction of any water course, or may, with the consent of the mayor and aldermen of cities or selectmen of towns, alter or change the location or grade of any highway, townway, public street or way of travel crossed by any aqueducts, conduits or pipes constructed under the provisions of this act, or in which such aqueducts, conduits or pipes may be located, subject to the same provisions as to holding cities and towns harmless as are contained in the last section.

SECTION 11. The said board may construct a storage reservoir on the South Branch of the Nashua river above the dam at the Lancaster Mills and over and near Sandy pond, which shall flood existing streets, roads, highways or other ways, and the Central Massachusetts and the Worcester, Nashua and Rochester railroads, now both operated by the Boston and Maine Railroad Company, in the towns of Clinton, Boylston and West Boylston; and as substitutes for the streets, roads, highways and other ways, except railways so flooded, the board shall construct new roads where necessary, near the margin of the said reservoir, the location, width, grade and manner of construction of said roads to be determined by mutual agreement between the said board and the selectmen of the towns or the county commissioners having authority over the same, or, if the parties cannot agree, the matter may be determined by an application of either party in writing to the Massachusetts highway commission, which is hereby authorized and directed to adjudicate finally upon the same.

SECTION 12. The said board may raise, alter or construct upon the present or a new location or locations, a railroad or railroads to take the place of the existing railroads where they will be either flooded or otherwise rendered unavailable by reason of the construction of said reservoir; but the location, grades and manner of raising, altering or constructing said roads shall be such as may be mutually agreed between the said board and the board of directors of the respective railroad companies interested, or it may contract with such companies acting by their directors for the raising, altering and construction of the railroads upon the location and in

the manner aforesaid. If the said board and the respective railroad companies cannot agree as to the location and manner of construction of said road, the matter may be determined by an application of either party in writing, to the Massachusetts board of railroad commissioners, which is hereby authorized and directed to adjudicate finally upon the same. All damages done to such railroad corporations under the provisions of this section shall be estimated in the manner provided in sections six and seven; but in estimating the damages sustained there shall be taken into account the amount of benefit the railroad company may have received from the separation of grades or change of location, or otherwise, if any. The said metropolitan water board is hereby authorized, acting for and in the name of the Commonwealth, with the approval of said board of railroad commissioners, to take in fee such lands and rights as may be necessary for constructing in a new location any part of the railroads aforesaid, and the said metropolitan water board shall and is hereby authorized and required to convey the lands so taken to the respective railroad companies, and said railroad companies may if they desire also locate their lines over the land so conveyed to them.

SECTION 13. The said board shall not reduce the flow of water in the South Branch of the Nashua River immediately above the dam at the Lancaster Mills to less than twelve million gallons in each and every week, and in permitting this amount of water to flow, the said board shall as far as practicable, supply the water at such times during the week as to meet the requirements of the owners of said dam.

SECTION 14. Nothing contained in this act shall be so construed as to prevent the towns of Clinton, Lancaster, Sterling, Boylston, West Boylston, Holden, Rutland, Princeton, Paxton and Leicester, or the city of Worcester, from taking from the South Branch of the Nashua River or its tributaries, or from the reservoirs constructed under the provisions of this act, so much of the water as they have already been or may hereafter be authorized to take by the legislature; but if before the taking of the water by any of the said towns or said city, the Commonwealth has taken and diverted the water of the river or has constructed works which will be used by or benefit the said town or city, then the said town or city shall pay to the said Commonwealth its fair proportion of the cost incurred by the Commonwealth for damages for the diversion of water or for the construction of the aforesaid works. If the metropolitan water board and the said city or town cannot agree as to the amount to be paid to the said Commonwealth, the matter may be referred by an application of either party in writing, to the commission to be appointed, as provided in section twenty-seven of this act and its decision shall be final.

SECTION 15. Any city, town or water company in the metropolitan water district may, before the introduction of a water supply by said board into said district, supply from its works any other city, town or water company in said district, upon such terms as may be mutually agreed upon between

the parties in interest, or it shall furnish such supply if so required by said board, to the extent that it can do so without endangering the sufficiency of the supply to the city or cities, town or towns regularly supplied from its works; and may, after the introduction of a water supply into the district as aforesaid, supply water as aforesaid, for such times and in such amounts as may be approved by the metropolitan water board in writing. In case of any disagreement as to the capability of the works for furnishing water the matter may be referred, by an application of either party in writing, to the state board of health for adjudication, and its decision as to the quantity of water to be supplied at such times and under such conditions as it may determine, shall be final. If an agreement cannot be made between the city, town or water company furnishing the water, and the city, town or water company receiving the water as to the sum to be paid for water, the matter shall be referred to the commission to be appointed by the supreme court as provided in section twenty-seven of this act for adjudication and its decision shall be final.

SECTION 16. Any city or town in the metropolitan water district shall have the right to use the water supplied by its own works without admixture with water from the metropolitan water supply if it shall so elect, provided the exclusion of the water of the metropolitan supply does not interfere with the carrying out of the plans reported and recommended by the state board of health in its report to the legislature of the year eighteen hundred and ninety-five.

SECTION 17. The metropolitan water board, acting in behalf of the Commonwealth, after taking the whole or any part of the water sources or water works of any city, town or water company, shall, in addition to all its powers under this act, as to such water sources and water works, have all the powers, rights and privileges which the said city, town or water company had at the time of said taking.

SECTION 18. All general laws relating to the water supply of cities and towns shall hereafter be equally applicable to the water supply of the metropolitan district, unless such application is inconsistent with the purposes of this act.

SECTION 19. The metropolitan water board shall furnish water for each city and town supplied by it, under sufficient pressure to supply the inhabitants of said city or town without requiring the city, town or water company supplying said city or town to pump the water, and it shall either discharge the water into a distributing reservoir or tank, or into a main pipe or pipes of said city, town or water company as said board may determine, and the connections between the metropolitan and local systems shall be subject to the direction and control of said board: *provided, however*, that nothing contained in this section shall be construed to authorize any city or town now supplied with water by a water company, to introduce water works supplied from the metropolitan system until it shall first have

acquired the works of the water company, or to prevent the metropolitan water board from furnishing water to any city, town or water company under a less pressure, by agreement with said city, town or water company.

SECTION 20. When any city or cities, or town or towns in the metropolitan water district shall take the franchise, works and property of any water company in said district, the compensation to be allowed and paid for the franchise of such company shall not be increased by reason of the provisions of this act.

SECTION 21. The state board of health is hereby authorized and required to make rules and regulations for the sanitary protection of the waters of the South Branch of the Nashua River, and any other waters taken or used by the metropolitan water board for supplying water to the metropolitan district, and may impose penalties for the violation of or non-compliance with these rules or regulations, not exceeding two hundred dollars in any one case to be recovered by complaint or indictment; and the metropolitan water board or its duly authorized agents may enter any lands, mills, factories, or other buildings for the purpose of ascertaining whether sources of pollution exist, and whether the rules and regulations made by the state board of health are complied with. On complaint by the metropolitan water board of the violation of said rules and regulations, the superior court in the county in which said violation is said to have occurred shall have jurisdiction to enforce the said rules and regulations by injunction or by other legal or equitable remedy. The rules and regulations made by the state board of health shall not take effect until they have been approved by the supreme judicial court for the Commonwealth.

SECTION 22. When the state board of health shall for the protection of the water supply of the metropolitan water district make regulations, the execution of which will require the providing of some public means of removal or purification of sewage, the metropolitan water board shall construct and maintain such works or means of sewage disposal, and the expense of such construction and maintenance shall be borne by the Commonwealth as part of the cost of construction and maintenance of the metropolitan water district water supply to be provided for and distributed under the provisions of this act.

SECTION 23. The metropolitan water board shall at all times keep full, accurate and separate accounts of its receipts, expenditures, disbursements, assets and liabilities, and shall include an abstract of the same in its annual report to the General Court.

SECTION 24. The state board of health shall, on the organization of the metropolitan water board, transfer and deliver over to said board, such plans, maps and other information acquired during the surveys and investigations as may be needed to give said board full information of the results of the surveys and investigations made by said board of health.

SECTION 25. The metropolitan water board is hereby authorized to utilize the fall of the water at the proposed dam to be built by it in the town of Clinton to produce and furnish power by any suitable means for use upon its works and for the use of the Lancaster Mills or its successors in said town, and it may produce and furnish power to the towns of Clinton and Lancaster and any person or corporation therein, or it may generate electricity and distribute the same to the towns of Clinton and Lancaster, or any person or corporation therein for any purpose: *provided, however*, that it shall not furnish or distribute power or electricity to said towns or any person or corporation therein, except the Lancaster Mills or its successors, without the consent of said towns, each for itself, obtained by vote of its inhabitants in town meeting. The said board is authorized to sell the power so furnished or supplied by contract or otherwise, and such contracts may be made for any length of time not exceeding fifteen years.

SECTION 26. To meet the expenses incurred under the provisions of this act, the treasurer and receiver-general shall, with the approval of the governor and council, issue from time to time scrip or certificates of debt in the name and behalf of the Commonwealth, and under its seal, for an amount not exceeding nineteen million dollars, for a term not exceeding forty years. Said scrip or certificates of debt shall be issued as registered bonds or with interest coupons attached, and shall bear interest not exceeding four per cent. per annum payable semi-annually on the first days of January and July of each year. Said scrip or certificates of debt shall be designated on the face as the Metropolitan Water Loan, shall be countersigned by the governor, and shall be deemed a pledge of the faith and credit of the Commonwealth, and the principal and interest shall be paid at the time specified therein, in gold coin of the United States or its equivalent, and said scrip or certificates of debt shall be sold and disposed of at public auction, or in such other mode, and at such times and prices, and in such amounts, and at such rates of interest, not exceeding the rate above specified, as the treasurer and receiver-general with the approval of the governor and council shall from time to time deem best. The treasurer and receiver-general shall, on issuing any of said scrip or certificates of debt, establish a sinking fund and apportion an amount to be paid thereto each year, sufficient with its accumulations to extinguish the debt at maturity. Any premium realized on the sale of said scrip or certificates of debt, shall be applied to the payment of the interest of said loan as it accrues.

SECTION 27. The supreme judicial court sitting in equity shall, upon the application of the metropolitan water board, after notice to each of the cities, towns and water companies in the metropolitan water district, appoint three commissioners who shall not be residents of said cities or towns, who shall, after due notice and hearing, and in such manner as they shall deem just and equitable, determine the proportion in which each

of said cities and towns shall annually pay money into the treasury of the Commonwealth for the term of five years next following the year of the first issue of said scrip or certificates, to meet the interest and sinking-fund requirements for each of said years, as estimated by the treasurer of the Commonwealth, and to meet the cost of maintenance and operation of said system for each of said years, as estimated by the metropolitan water board and certified to said treasurer. In making their award the commissioners shall take into account the extent to which the sources or works belonging to the separate municipalities are used for furnishing, storing, pumping and conveying the water supplied to the metropolitan district by the metropolitan water board, and shall also take into account the capacity of the sources and works retained by any city, town or water company, for the supply of the city or cities, town or towns now supplied by them, and the amount of water actually supplied therefrom; and when said award shall have been accepted by said court, the same shall be a final and conclusive adjudication of all such matters herein referred to said commissioners, and shall be binding on all parties. When any city or cities, town or towns, or parts thereof, are supplied with water by a water company the said water company shall pay the sum apportioned to the city or cities, town or towns supplied by it, and in case said water company shall furnish only a part of the water supplied to said city or cities, town or towns, it shall pay such proportion as may be fixed by said commissioners. The said commissioners shall also, in the manner aforesaid, adjudicate the matters which may be brought before them under the provisions of sections fourteen and fifteen, and its award when accepted by said court shall be final and conclusive. In the discharge of their duties the said commissioners may employ experts to advise them at the expense of the Commonwealth.

Section 28. Before the expiration of said term of five years and every five years thereafter, three commissioners, who shall not be residents of any of the cities or towns constituting the metropolitan water district, shall be appointed as aforesaid, who shall in the manner aforesaid determine the proportion in which each of said cities, towns and water companies shall annually pay money into the treasury of the Commonwealth, as aforesaid, for the next succeeding terms of five years, together with any deficiency in the amount previously paid in, as found by said treasurer, and shall return their award into said court; and when said award shall have been accepted by said court, the same shall be a final and conclusive adjudication of all matters herein referred to said commissioners and shall be binding on all parties.

Section 29. The metropolitan water board shall annually estimate the cost of maintenance and operation of the works under its charge for the ensuing year, and certify the same to the treasurer who shall apportion said expenses in the manner provided in the following section.

SECTION 30. The amount of money required each year from each city and town and water company of the metropolitan water district to meet the interest, sinking-fund requirements and expenses aforesaid, shall be estimated by the treasurer of the Commonwealth in accordance with the proportion determined as aforesaid, and shall be included in and made a part of the sum charged to each city or town, and be assessed upon it in the apportionment and assessment of its annual state tax, excepting such portions or the whole of the assessment against any city or town as are by the provisions of this act to be paid by the water company supplying said city or town or a part thereof; and said treasurer shall in each year notify each city and town and water company of the amount of such assessment and the same shall be paid by the city or town into the treasury of the Commonwealth at the time required for the payment of its state tax, and by the water company in quarterly payments on or before the last day of the third, sixth, ninth, and twelfth months of the calendar year.

SECTION 31. The metropolitan water board may, from time to time, by public or private sale, dispose of any property, real or personal, no longer needed for the construction or maintenance of the works under its charge; and the net proceeds of such sales, after deducting all necessary expenses incurred thereby, shall be paid into the treasury of the Commonwealth, and if any part of the appropriation or fund from which the payment for such property was originally made remains unexpended, shall be credited to said appropriation or fund, and otherwise shall be credited to and become a part of the sinking fund established under this act. Any other income or receipts derived from any operations carried on under the direction of said board shall be paid into the treasury as aforesaid and shall be applied to the payment of the interest on the metropolitan water loan as it accrues.

SECTION 32. The supreme judicial court shall have jurisdiction in equity to enforce the provisions of this act and shall fix and determine the compensation of all commissioners, and of experts employed by them, appointed by said court under the provisions hereof.

SECTION 33. Whoever wantonly or maliciously corrupts, pollutes or diverts any of the water or any part thereof taken under this act, or injures any structure, work or other property owned, held or used by the Commonwealth under the authority and for the purpose of this act, shall forfeit and pay to the Commonwealth three times the amount of damages resulting therefrom, to be recovered in an action of tort brought in the county where the prohibited act is done, and this section shall apply to corporations as well as to natural persons.

SECTION 34. Whoever wantonly or maliciously corrupts, pollutes or diverts any of the water or any part thereof taken under this act, or injures any structure, work or other property owned, held or used by the Commonwealth under the authority and for the purpose of this act shall in

addition to the forfeiture of treble damages provided for in the thirty-third section of this act, on indictment and conviction be punished by fine not exceeding five thousand dollars, and by imprisonment not exceeding ten years in the house of correction, or in the state prison, in the discretion of the court; and this section shall, so far as may be, apply to corporations as well as to natural persons.

SECTION 35. This act shall take effect upon its passage.

REPORT OF THE CONSULTING ENGINEER.

BOSTON, Feb. 5, 1895.

To H. F. MILLS, A.M., C.E., *Chairman of Committee on Water Supply and Sewerage of the State Board of Health.*

SIR: — Your chief engineer, Mr. Stearns, has asked me to give my views regarding the best source from which to draw an additional supply of water for the cities and towns within what has been denominated the "metropolitan district," and also upon the scheme of works proposed by him for utilizing the waters of the Nashua River.

Investigations made for the city of Boston, some twenty years ago, make me acquainted with most of the sources within fifty miles of the city, discussed in his report.

Last summer I visited with him the basin of the proposed reservoir on the Nashua, and examined the sites of the dam and dikes and the area to be overflowed. Since then I have discussed with him, from time to time, various plans and questions relating to methods of construction, capacity of conduits, etc., and have read with care the reports and estimates placed in my hands.

Mr. Stearns, on page 6 of his report, gives a table showing that the average daily capacity in a dry year of the works now supplying the metropolitan district is 83,700,000 gallons; that the average daily consumption of water in this district was, in 1894, 79,046,000 gallons, and that the estimated consumption in 1898 is 100,026,000 gallons. These figures point out, with more force than any argument can give, the necessity for prompt action to secure an additional supply. The table also shows that this is a need not only of the district as a whole, but also of a majority of the cities and towns comprising it.

General considerations would lead to the belief that this additional supply could be more economically obtained by joint than by independent action; and Mr. Stearns has pointed out, with considerable detail, the advantages to be gained in saving of cost and in purity of

water by building a single system of works to bring the supply from a source of large capacity.

Considering the state of the existing supplies as to quantity and quality, the rate of growth of the populations and the increasing use of water per capita, it seems clear that the new source should have a capacity to supply not less than 100,000,000 gallons per day as an addition to the existing supplies that may be retained in use; and, unless of much greater capacity than above mentioned, it is desirable that it should be so situated that its supply may be largely supplemented in a not distant future by providing a larger volume of storage on its water-shed or by connecting other sources with it.

Of the sources available for supplying the metropolitan district, all but the Nashua, the Charles and the Merrimack rivers, Lake Winnipiseogee in New Hampshire and Sebago Lake in Maine, may be thrown out of consideration as obviously inferior either for want of capacity or because they would furnish unacceptable water; and on closer examination it is found that the Charles, although it has a drainage area above the suggested point of taking of 156 square miles, would not furnish a large supply. By building a dam at South Natick, and others higher up in the water-shed, it is probable the average daily yield of the Charles could be brought to 100,000,000 gallons, but the whole of it would not be available for a supply to the metropolitan district.

From 20,000,000 to 30,000,000 gallons per day should be allowed to flow in the river bed for the benefit of the cities and towns on its lower reaches. Its available capacity of supply may be taken at 75,000,000 gallons per day.

Water to be derived from this source, as compared with that from the Nashua, would be much inferior in quality. The population per square mile of water-shed is much larger, the water as it flows in the river has a higher color, and, above all, the opportunity for purification would be very much less in the shallow storage basin that might be built in the valley of the Charles than in the very large and deep basin proposed for the Nashua.

The Charles, therefore, may also be set aside from further consideration, for deficiency both in quantity of supply and in good quality of water.

The Merrimack River would furnish an abundant supply for all time, as its dry-weather daily flow at Lowell is estimated at fully 1,000,000,000 gallons. But experience at Lowell and Lawrence

has demonstrated that the unpurified water is not safe for domestic use; to make it so, it must be filtered.

The works for diverting the water from the river and conveying it to Spot Pond would consist of a pumping station at the river, a conduit from the river to the filter beds, covered filter beds in Wilmington, a conduit from this point to a pumping station in Woburn, and force mains and conduit between this pumping station and Spot Pond.

In estimating the value of this river as a source of supply, careful consideration must be given to the polluted condition of the water and to the difficulties to be met in operating and maintaining the works for purifying and conveying the supply.

It is plain that, with a pumping station on the Merrimack, filters at Wilmington and a second pumping station at Woburn, at each of which places a considerable force of men must be employed, efficient administration would be more difficult and the possibility of an interruption to the service would be greater than with a gravitation supply. The cost of operating per million gallons supplied would, of course, be high, as the water must be both filtered and pumped.

Experience abroad, and for one year with the supply to the city of Lawrence in this State, seems to demonstrate that water which has been considerably contaminated by sewage may be rendered reasonably safe for domestic use by filtering through sand. But the process must be thorough; that is, it must be carried on conscientiously and under skilful management. The consequences of carelessness or inefficiency may be so serious that it appears quite unwise to select for a supply a polluted water that must be filtered, when sources yielding uncontaminated water can be utilized at a reasonable cost.

The Merrimack as a source of supply must therefore be considered inferior to the Nashua.

Either Lake Winnipiseogee or Sebago Lake would furnish an abundant supply of very pure water. Both of them, however, are outside the limits of this State, and the cost of works for bringing their waters to the metropolitan district, even if the right to do so could be obtained, would be so large that they must be classed as inferior to the Nashua as desirable sources of supply to this district.

Mr. Stearns, in a chapter of his report entitled "General remarks regarding sources of water supply," makes an excellent statement of the general considerations that govern the selection of a source of

water supply for domestic purposes; and in later chapters he demonstrates that a practically unlimited supply of very pure water may be obtained at a reasonable cost for works from the South Branch of the Nashua River and other water-sheds that can be readily connected with it.

He also describes the works that he recommends to be built to impound and purify the water and convey it to and distribute it throughout the metropolitan district. He gives an estimate of the cost of the works, and, as a basis for the estimate, he has made designs for the dam, dikes, conduits and other structures.

I have studied the general scheme of works and examined the designs of details and the estimates of cost with sufficient care to feel justified in saying I am of opinion that the general scheme is a good one, that the designs are ample for the purpose and well conceived, and that the estimates of cost are reliable.

Considering the quantity, quality and cost of supply, I believe that the South Branch of the Nashua River is by far the best available source from which to draw an additional supply of pure water for the metropolitan district.

Respectfully submitted,

JOS. P. DAVIS,
Consulting Engineer.

REPORT OF THE CHIEF ENGINEER.

To H. F. Mills, A.M., C.E., *Chairman of Committee on Water Supply and Sewerage of the State Board of Health.*

Sir: — At the meeting of the State Board of Health on July 6, 1893, I was directed to take charge, as chief engineer, under the supervision of your committee, of the investigations relative to procuring a water supply for the city of Boston and its suburbs. The State Board of Health was authorized to make these investigations by chapter 459 of the Acts of 1893, and their nature is indicated by sections 1 and 2 of this chapter, which are as follows: —

Section 1. The state board of health is hereby authorized and directed to investigate, consider and report upon the question of a water supply for the city of Boston and its suburbs within a radius of ten miles from the state house, and for such other cities and towns as in its opinion should be included in connection therewith.

Section 2. The said board shall forthwith proceed to investigate and consider this subject, including all questions relating to the quantity of water to be obtained from available sources, its quality, the best methods of protecting the purity of the water, the construction, operation and maintenance of works for storing, conveying, or purifying the water, the cost of the same, the damages to property, and all other matters pertaining to the subject.

In order to make these investigations, the engineering force of the Board was largely increased, with the approval of your committee. Mr. Albert F. Noyes, for seventeen years city engineer of Newton, was engaged as assistant chief engineer, to relieve me as far as practicable of the regular engineering work of the Board relating to water

supply and sewerage of cities and towns throughout the State, so that I might give more personal attention to the investigations for a new water supply for the metropolitan district; and to assist in making these investigations. Mr. Thomas F. Richardson, who was engaged from 1873 to 1879 in investigations for a new water supply for Boston and upon the construction of the Sudbury River aqueduct, and who has since had an extended experience in the West, was engaged as principal assistant engineer. Messrs. X. H. Goodnough, William M. Brown, Jr., Sidney Smith, Arthur T. Safford, Horace Ropes, Morris Knowles, Chester W. Smith, B. F. Hancox, Jr., and Marshall Nevers have also been employed upon the work, in charge of special investigations, of surveying parties in the field or of office work.

Mr. Dexter Brackett, who has been connected with the engineer's department of the city of Boston for the past twenty-five years, nearly all of the time in connection with the water supply of the city, has, by my request, made reports upon the probable future consumption of water in the metropolitan district, and upon the feasibility of supplying in the district water of different qualities for different purposes, as, for instance, a spring or ground water for drinking and cooking only, and an inferior water, not safe for drinking, for mechanical and manufacturing purposes, sprinkling streets, and other similar uses.

Mr. Desmond FitzGerald, resident engineer of the additional water supply of the city of Boston, has, in accordance with a similar request, made a report upon the extent to which the water of the Sudbury River can be improved by the drainage of the swamps upon its water-shed, and the cost of such improvement.

Mr. Allen Hazen, who has had a large experience in the filtration of water and sewage as chemist in charge of the Lawrence Experiment Station of the State Board of Health, and who has recently spent a year in Europe examining water filtration systems and ground water supplies, was requested to advise with regard to the purification of the Merrimack River water by filtration through sand.

Mr. Charles T. Main of the firm of Dean and Main was engaged to advise with regard to the value of the mills upon the Nashua River, which would be flooded by a proposed reservoir above Clinton.

Mr. Joseph P. Davis, the consulting engineer of the State Board of Health, was asked at the beginning of these investigations to advise

with regard to them as they progressed, and finally to make a report as consulting engineer.

The chemical analyses referred to or printed in this report were made under the direction of Dr. Thomas M. Drown, chemist of the Board.

In making my investigations for a new water supply, I have thought it best to include all of the cities and towns situated within ten miles of the State House, and, in addition, the town of Swampscott, which is intimately connected with the city of Lynn. For convenience this collection of cities and towns will be termed in my report the "metropolitan district."

The results of my investigations and consideration of the subject will be presented in the following order: —

1. Statistics and estimates relating to the water supply of the metropolitan district as a whole.

2. A statement of the present condition of the water supply of each of the cities and towns in the district, prefaced by some remarks regarding sources of water supply in general.

3. An outline of the plan recommended for taking an additional water supply from the Nashua River.

4. A financial statement with regard to the existing water works of the district.

5. A statement with regard to each city and town in the district, as to whether it should obtain its water supply independently or as a part of the district.

6. A statement regarding sources investigated but not recommended.

7. A detailed description of the works recommended, both for bringing water to the metropolitan district, and for distributing it to the cities and towns within the district, including estimates of cost.

List of Cities and Towns within Ten Miles of State House.

The following list includes the towns within the ten-mile limit, with the population of each as given by the census of 1890 and the estimated population in 1895 and 1898. The dates 1895 and 1898 are selected as representing respectively the population at the time when this report will be before the Legislature and the population at the earliest date at which a metropolitan supply can become available.

CITY OR TOWN.	Population in 1890.	Estimated Population.	
		1895.	1898.
Boston,	448,477	504,702	541,532
Cambridge,	70,028	80,917	87,807
Lynn,	55,727	61,146	67,982
Somerville,	40,152	51,583	58,658
Chelsea,	27,909	30,975	32,850
Newton,	24,379	28,470	32,809
Malden,	23,031	30,240	35,196
Waltham,	18,707	21,700	23,500
Quincy,	16,723	22,140	26,152
Woburn,	13,499	14,701	15,962
Brookline,	12,103	15,638	17,913
Medford,	11,079	14,812	17,685
Everett,	11,068	17,750	21,920
Hyde Park,	10,193	12,300	13,740
Melrose,	8,519	11,656	13,677
Watertown,	7,073	7,551	8,420
Wakefield,	6,982	8,119	8,996
Stoneham,	6,155	7,072	7,704
Revere,	5,668	7,707	9,461
Arlington,	5,629	6,573	7,519
Winchester,	4,861	6,930	7,782
Milton,	4,278	5,800	6,730
Saugus,	3,673	4,638	5,290
Lexington,	3,197	3,645	4,104
Winthrop,	2,726	3,783	4,691
Belmont,	2,098	2,628	3,256
Nahant,	880	1,125	1,203
Total, 27 cities and towns,	844,814	984,301	1,082,539

The towns of Lexington and Dedham each have one village within the ten-mile limit, so that it was a question whether to include them or not. It was thought best to include the town of Lexington in the district, because of the difficulty of obtaining a sufficient independent water supply for this town; while Dedham has been

omitted, because it has a more ample water supply and a better opportunity for obtaining an additional supply.

Towns outside the Ten-mile Limit considered with Reference to including them in the Metropolitan District.

Outside of the ten-mile limit there are several towns which may have to obtain their water supply from the metropolitan district. These are Swampscott, Reading, Marblehead, Wellesley and Dedham. Of these places it was thought best to include in the district the town of Swampscott, which has only a limited water supply, and is closely connected with the city of Lynn, so that it could be supplied in connection with that city without difficulty. There were some reasons for including also Reading, Marblehead and Wellesley, but they are less closely connected with the district, and are not so large but that they could be included later without any serious modification of the plans.

Consumption of Water in the Metropolitan District, and Capacity of Present Sources of Water Supply.

The following table gives the amount of water consumed by the different communities in the metropolitan district in 1890 and 1894, and the amount which would be consumed in 1898, if the increase from 1894 to 1898 were the same as from 1890 to 1894; also the estimated capacity of the sources now supplying the district.

The capacity of the sources, as given in the last column of the table, is the capacity in a very dry year and with the works as they existed in 1894. In wetter years the capacity would be considerably greater; but it is a well-established principle, in supplying water to large communities, that the capacity of the sources should be reckoned upon the driest year which is likely to occur, so that the supply of water may not be interrupted. The interests at stake are altogether too great to warrant the adoption of any other policy. The capacities as stated in the table are also, in some instances, somewhat less than the actual minimum capacities of the sources, the reduction being made in order to give the proper relation between the capacity and the *average* consumption for the whole year, which is less than the consumption during the portions of the year when the capacities of these sources are most severely taxed.

Comparison of Amount of Water Consumed in the Metropolitan District with the Present Capacity of Sources of Supply.

CITY OR TOWN.	AVERAGE DAILY CONSUMPTION.		Estimated Average Daily Consumption, 1898.	Average Daily Capacity of Sources.
	1890.	1894.		
	(Gallons.)	(Gallons.)	(Gallons.)	(Gallons.)
Boston (Cochituate works),	33,872,000	46,576,000	59,280,000	48,000,000
Charlestown, Somerville, Chelsea and Everett (Mystic works),	8,301,000	10,282,000	12,263,000	7,000,000
Cambridge,	4,566,000	5,777,000	6,988,000	7,200,000
Lynn and Saugus,	2,657,000	4,020,000	5,383,000	3,450,000
Newton,	985,000	1,623,000	2,261,000	2,000,000
Malden,	*	1,460,000	1,800,000	1,520,000
Waltham,	626,000	1,237,000	1,848,000	3,100,000
Quincy,	497,000	798,000	1,099,000	840,000
Hyde Park and Milton,	391,000	587,000	783,000	600,000
Woburn,	777,000	972,000	1,167,000	1,000,000
Wakefield and Stoneham,	537,000	*	800,000	660,000
Brookline,	877,000	1,325,000	1,779,000	3,100,000
Medford,	*	699,000	950,000	900,000
Revere and Winthrop,	427,000	774,000	1,121,000	800,000
Melrose,	581,000	681,000	781,000	800,000
Watertown and Belmont,	360,000	414,000	468,000	550,000
Arlington,	*	*	450,000	750,000
Winchester,	*	*	430,000	900,000
Swampscott and Nahant,	229,000	324,000	419,000	300,000
Lexington,	*	*	190,000	230,000
Total,	55,683,000	77,549,000	–	–
Estimated consumption in places marked with an asterisk,	2,135,000	1,497,000	–	–
Total for metropolitan district,	57,818,000	79,046,000	100,026,000	83,700,000

A comparison of the average daily consumption of water in the whole district in 1894 with the aggregate capacity of the sources shows that the capacity is very little in excess; and, if the consumption increases from 1894 to 1898 at the rate that it did from 1890 to 1894, there will be a deficiency in the whole district of about 16,000,000 gallons per day, which will have to be met by additions to existing works or by the restriction of waste.

The extent to which the capacity of existing sources may be increased will be referred to in a subsequent chapter, giving in detail the present condition of the water supply of each of the cities and towns in the district, and the opportunities for increasing the supply by independent action. It is sufficient in this general statement to say that, even with complete development of existing sources, it will be difficult, if a very dry year should occur, to provide all the water needed up to the earliest date when a metropolitan supply may be made available, *even if those places which now have a surplus of water should assist those insufficiently supplied;* and it is therefore of the utmost importance that there should be no delay in procuring a new and ample supply.

Future Population and Consumption of Water in the Metropolitan District.

Appendix No. 1 contains a complete statement of the past, present and estimated future population of the metropolitan district; and Appendix No. 2, which is a paper by Mr. Dexter Brackett upon the subject of the consumption of water, contains an estimate of the amount of water that should be allowed for each inhabitant.

By a combination of the future population with the amount of water to be provided per inhabitant, the total amount of water required to supply the metropolitan district in the future may be obtained. An estimate of this kind is necessary in order to fix the sizes of aqueducts and other works with reference to true economy; that is, in order not to make them so small that they will soon be outgrown, or so large as to provide for an unnecessary length of time in the future. It is obvious, however, that the future growth of population may be governed by many circumstances which cannot be foreseen, so that the future population may differ much from the best estimate that can be made. It is also true that the amount of water which will be used per inhabitant in the future is liable to differ as

much from any present estimates as the future population. Therefore, while I give in a table below the estimated population and consumption of water for every five years from 1895 until 1930, I have ever had in mind in making the investigations that the amount of water required at any future period might be much more or less than the estimated amount.

Estimated Population and Consumption of Water in the Metropolitan District for Each Five Years from 1895 to 1930.

YEAR.	Estimated Population.	Daily Consumption per Inhabitant.	Total Daily Consumption.
		(Gallons.)	(Gallons.)
1895, ...	984,301	85	84,000,000
1900, ...	1,148,033	90	103,000,000
1905, ...	1,328,787	94	125,000,000
1910, ...	1,526,623	97	148,000,000
1915, ...	1,743,510	99	173,000,000
1920, ...	1,979,930	100	198,000,000
1925, ...	2,238,500	100	224,000,000
1930, ...	2,521,875	100	252,000,000

General Remarks regarding Sources of Water Supply.

It is proposed in the chapter which follows this one to consider the present condition of the water supply of each of the cities and towns in the metropolitan district, and the opportunities for increasing the supply by independent action. I have thought it would aid those not intimately acquainted with the subject of water supply to a better understanding of the statements in that chapter, and would lead to the avoidance of repetition, to first make a brief statement with regard to sources of water supply in general.

Sources may be divided into two general classes: those in which the supply is taken from the ground, known as ground waters, and those obtained from lakes, ponds, streams and storage reservoirs, known as surface waters. As a general statement, it may be said that the quantity of water to be obtained from the ground is quite limited, Newton, with a population of 24,379 in 1890, being the largest place within the State supplied in this way; and the amount to be obtained from any given place cannot be predicted as accurately as in the case of surface waters.

Ground water supplies in this State are generally collected by means of large excavated wells, filter galleries or small tubular wells sunk to a moderate depth in porous ground; and the quality of water obtained by each of these methods is practically the same. In order that ground water may not deteriorate in quality after being taken from the ground by the growth in it of minute vegetable organisms, it is necessary to keep it from exposure to the light.

Some ground waters are derived mainly or wholly from the rain which falls upon the territory draining toward the well or filter gallery and sinks into the ground to percolate gradually to the well, while others are derived mainly by filtration from a stream or pond near by. In many cases the water percolating from a stream or pond is purified by its passage through the ground, so that it cannot be distinguished from a true ground water.

Ground water in unpopulated regions, where the mineral matter in the ground is of such a character that it does not dissolve and make the water hard, is better than any water which can be obtained from surface sources, because the water is wholly free from the minute organisms which at times cause disagreeable tastes and odors in nearly all surface waters, and also because the amount of soluble organic matter found in such ground waters is very small. There are, however, cases in which a ground water is not satisfactory. If the source of supply is situated in a populous district, where much foul water is turned into the ground through cesspools or otherwise, or is near a polluted stream or pond, the source is open to suspicion, even though chemical analysis may show that the organic matter has been very nearly all removed from the water by filtration; and the water may also be objectionable by reason of the hardness caused by the salts contained in the foul water, which cannot be removed from the water by filtration.

A ground water may also be objectionable, owing to the presence of iron and other substances which are found in water which has been in contact with decomposable organic matter in the absence of free oxygen. These waters, which for convenience are termed "iron" waters, are sometimes found when wells are sunk in swampy places, or in soil containing vegetable matter, like the deposits of silt along the banks of the Merrimack River; and in some instances continuous filtration for a long time from a body of surface water to a well has resulted in changing the character of the filtered water from a good ground water to an iron water.

There are some indications that all filtered river waters will after a sufficient time be affected in this way; but the experience at Waltham, Newton, Woburn and some other places shows that filtration from a surface source to a well may continue for twenty years without the filtered water showing signs of deterioration, and it is not known but that the filtration may continue to be satisfactory for a very much longer time. The fact that deterioration has occurred in some instances, however, shows that there is danger in any case that the water obtained in this way may become at some time unsuitable for use.

Surface water derived from a water-shed which contains few inhabitants or none, and is free from swamps in which the water can stand in contact with vegetable matter, is a satisfactory water for all the purposes of a public water supply; but, as before indicated, it is not equal in quality to the better class of unpolluted ground waters which may have been rendered nearly pure organically by the filtration of the water through the ground.

If a surface water is polluted by sewage it becomes dangerous to the health of the community consuming the water. The greatest danger occurs when the water is supplied to the consumer very soon after the polluting matter enters it; as, for instance, where water is pumped directly from a polluted running stream into the pipes which convey the water supply to a town. If, on the other hand, the water after being polluted is stored for a long time in a large storage reservoir, or passes through a series of reservoirs, so that there is opportunity for the sedimentation or death of the infectious matter, the water is thereby rendered safer for use. A polluted surface water may also be purified by filtration through artificial sand filters, if they are properly constructed and operated.

If a surface water is taken from a water-shed containing many swamps, it will contain a large amount of dissolved organic matter and will have a brownish color. It is not known that such water is unwholesome, but it is not attractive to the water consumer either in appearance or taste. The improvement of such water may be effected both by the drainage of the swamps, so that the water will not stand in them, and by storage in reservoirs sufficiently large to permit the bleaching of the water and the decomposition of the organic matter in it. So far as I know, the drainage of swamps upon a large scale has not yet been tried: but I see no reason to doubt that it will prove effective in improving the taste and appearance of such

water. The water does not bleach to any considerable extent by storage in a reservoir if its capacity is small, so that the water is changed as often as once in two or three months in the summer season; but a marked effect is noticed in cases where the water is not changed on the average oftener than once in eight months; and by storage for a year or more a water which is not too dark originally will be rendered very nearly colorless.

Water stored either in a pond, lake or reservoir is liable to contain at times growths of very minute animal or vegetable organisms, which give the water an objectionable taste and odor. There are many conditions which affect the frequency and extent of these growths, of which the most important seems to be the abundance of the supply of suitable nitrogenous food. This food may be furnished either by the nitrogenous matters contained in the water entering the reservoir, or it may be derived from the organic matter in the bottom of the reservoir.

When a pond or reservoir receives its supply from a thickly populated district, the water entering the reservoir is almost certain to contain enough food to produce an abundant growth of organisms; and in the case of reservoirs constructed without the removal of the soil and vegetable matter from the area flowed, a similar effect may be produced on account of the nitrogenous matter taken up by the water from the bottom of the reservoir. It might be expected that the bad effects of neglecting to properly prepare a reservoir for the reception of water would pass away in a few years, and in some cases this has been the result; but in others growths of organisms have occurred year after year, with little or no diminution, for as many as twenty years. In ponds and well-prepared reservoirs supplied with unpolluted water these growths occur but seldom, and as a rule do not seriously affect the water; so that it is important from the standpoint of taste and odor, as well as of health, that unpolluted sources should be selected, and that the reservoirs should be carefully prepared for the reception of water by the removal of all soil and vegetable matter.

The quantity of surface water which may be obtained from a given source depends upon the extent of the drainage area or water-shed of the source, the amount of rainfall upon it, the proportion of the rainfall which finds its way into the streams, and the amount of water which can be stored in the wetter portions of the year for use during the drier portions. The rainfall in a series of years differs but little

in amount from place to place in eastern Massachusetts; and experience has shown that there is not very much difference in the amount of water which eventually finds its way into the streams per square mile of different water-sheds. It is therefore feasible to estimate with a considerable degree of accuracy the amount of water which given water-sheds in connection with given amounts of storage will furnish, by using as a basis the accurate records kept by the city of Boston of the quantity of water which has flowed per square mile from the Sudbury River water-shed during each month of the past nineteen years.

In the case of large communities which are wholly dependent for water upon their public water supply, it is obviously necessary that the supply should not be deficient at any time; and it is therefore necessary to base all estimates of capacity of sources upon the records of the driest years or series of years which have occurred, and not upon the average of the records. It is extremely fortunate for this purpose that the Sudbury River records include two years, 1880 and 1883, which were drier than any other years in the last forty or fifty. Where the capacities of surface water sources are given in this report, they are based upon utilizing all available storage in the driest year or series of years included in the Sudbury River records, and due allowance has been made for evaporation from water surfaces, for filtration past dams, and other causes which affect the quantity of water which a source will supply.

In the case of ground-water supplies the capacity has been estimated from the best available information. In most ground-water supplies the capacity of the source is less in summer than at other seasons of the year; and it is at this time that the consumption of water, particularly in the suburbs, where much water is used for watering lawns, is liable to be the greatest. In comparing the capacity of a ground-water source with the consumption of water, it is therefore necessary to take into account the amount of water consumed in the drier portions of the year, rather than the average consumption for the whole year. This is much less necessary in similar comparisons with surface-water supplies, because, usually, the amount of water stored is sufficient to maintain the supply for a much longer period.

Most of the larger ground-water supplies in the vicinity of Boston are taken from works located by the side of a river or pond, and much of the water is derived by filtration from this surface-water

source. The capacity of the source, therefore, depends upon the amount of water which will filter into and through the ground from the bed of the river or pond, and upon the amount of rain which falls upon the territory from which water percolates directly to the source. It is of course true that in many cases the means of taking water from the ground do not equal the supply to the ground; but, as soon as the works for drawing water from the ground have sufficient capacity to take all of the water which the ground in the locality will furnish, it is obvious that no multiplication of wells will increase the supply to any large extent.

It may be feasible, however, to facilitate the filtration of water from a surface source into the ground, and to do so in such a way that the water so filtered will become as thoroughly purified as that which filters by the natural course. The best way for doing this, in cases where the topography and character of the ground will permit, is to pump the water in comparatively small quantities per acre upon dry, porous land back of the filter gallery or wells, and there distribute it evenly and intermittently upon suitably prepared beds, so that it will filter into the ground. This is a method which has not, so far as I know, been tried upon a large scale in this country; but, from the information now in existence with regard to the filtration of water, it seems altogether probable that satisfactory results may be obtained in this way. It may be necessary, however, to adopt special precautions to prevent the filtration from being interrupted during cold winters.

The most important ground-water supplies in the vicinity of Boston are along the banks of the Charles River, where the water supplies of Needham, Dedham, Brookline, Newton, Wellesley, Waltham and Watertown are obtained. The Legislature has already granted to these towns the right to take 15,000,000 gallons of water per day from this river.*

Measurements of the flow of Charles River at Newton Upper Falls from Aug. 21 to Oct. 14, 1845, showed an average daily flow during fifty days when gaugings were taken of 26,500,000 gallons, and an average daily flow during the whole month of September of only 19,100,000 gallons. It is probable that these measurements do not represent the minimum flow of the stream.

* The town of Wellesley is not restricted as to the amount of water which it may take, but for the purposes of this estimate the quantity is assumed to be 1,000,000 gallons per day.

It will therefore be seen that the amount of water to be obtained from these ground-water supplies near the Charles River may be limited not only by the amount which can be made available from the storage in the interstices of the porous ground, and which can be filtered through the ground to the works, but also by the yield of the river at times of extreme drought, unless some provision is made for increasing the minimum flow of the river by storage reservoirs upon it or its branches.

Present Condition of the Water Supply of the Cities and Towns in the Metropolitan District, and the Opportunities for increasing the Supply by Independent Action.

The different water supplies of the different communities will be described in the order of their size, as follows: —

Boston, exclusive of Charlestown district (Cochituate Works).
Charlestown, Somerville, Chelsea and Everett (Mystic Works).
Cambridge.
Lynn and Saugus.
Newton.
Malden.
Waltham.
Quincy.
Hyde Park and Milton.
Woburn.
Wakefield and Stoneham.
Brookline.
Medford.
Revere and Winthrop.
Melrose
Watertown and Belmont.
Arlington.
Winchester.
Swampscott and Nahant.
Lexington.

Boston, Exclusive of Charlestown District.

[Population in 1890, 410,129; estimated population in 1895, 463,069.]

Description and Capacity of Sources of Supply. — The portion of Boston above indicated is supplied with water from Sudbury River and Lake Cochituate, and the works for taking water from both of these sources are known collectively as the "Cochituate Works."

The total drainage area of these sources is 94.07 square miles. The water from the Cochituate water-shed is stored in Lake Cochit-

uate, and that from the Sudbury River water-shed in five artificial storage reservoirs, and in Whitehall Pond, which is partly artificial. In addition to these reservoirs, another one, which will have a capacity nearly equal to the aggregate capacity of all of the reservoirs now in use, is being constructed. This is known as Reservoir No. 5.

The daily capacity of the works, as now constructed, is, in a very dry year, 48,000,000 gallons per day, and when the new reservoir (No. 5) is completed and filled will be 62,000,000 gallons per day. These figures represent the amounts which, if drawn every day in the year, would just empty the reservoirs in the driest years which have occurred since the Sudbury River was first used as a source of water supply, and these years are as dry as any in the last forty or fifty. This basis of reckoning the capacity of the sources is the one commonly used, and is therefore adopted in this report, though a proper regard for the *quality* of the water supply requires that the reservoirs should not be emptied, as it necessitates supplying water to the city which has not had the benefit of storage in a reservoir. In years of ordinary rainfall the Cochituate Works would furnish the quantities above stated without drawing the reservoirs to an extremely low level.

Consumption of Water. — The average daily consumption of water from the Cochituate Works during the past five years has been as follows: —

Consumption of Water, Cochituate Works.

YEAR.	Population supplied.	Annual Increase (Per Cent).	Average Daily Consumption (Gallons).	Annual Increase. Gallons.	Annual Increase. Per Cent.	Average Daily Consumption per Inhabitant (Gallons).
1890, . . .	410,129		33,872,000			83
		4.1		3,815,000	11.3	
1891, . . .	427,231		37,687,000			88
		3.3		3,625,000	9.6	
1892, . . .	441,232		41,312,000			94
		2.3		6,141,000	14.9	
1893, . . .	451,399		47,453,000			105
		1.2		877,000*	1.8*	
1894, . . .	456,606		46,576,000			102

* Decrease.

NOTE. — All populations after 1890 are estimated, and the population in 1894 does not include Charlestown, which was supplied with water from the Cochituate Works from Sept. 12, 1894, until the end of the year.

It will be noticed that the daily consumption for the past two years, as given in the above table, is substantially the same as the daily capacity of the existing works in a very dry year; and if the consumption should increase in the near future at the same rate that it has from 1890 to 1894, the capacity of the works, as they will be developed by the construction of Reservoir No. 5, would be reached in 1899.

If the Cochituate Works had to supply in the future only the territory now supplied by them, the more effective restriction of waste might defer for a short time the necessity of constructing works to furnish an additional supply; but this is not the case, as the Charlestown district of Boston, and the cities of Somerville, Chelsea and Everett are now supplied by the city of Boston with water from Mystic Lake, which is of unsatisfactory quality and inadequate in quantity. In a year no drier than that which has just passed * it has been found necessary to use a temporary pump at Mystic Lake to raise water into the aqueduct leading to the main pumps, and to supply Charlestown with water from the Cochituate Works for several months. Under these circumstances it is obviously improper for the city of Boston to depend wholly upon the restriction of waste to prevent a shortage of water.

Quality of Water. — The streams which feed Lake Cochituate supply water of nearly the same character as those which feed the storage reservoirs upon the Sudbury River; but Lake Cochituate furnishes a water having but little color, while the Sudbury River reservoirs furnish water having a marked brownish tinge. This difference is due to the fact that Lake Cochituate has a much larger storage capacity in proportion to the quantity of water entering it than the

* Although the year 1894 has been much drier than the average year, the flow from the Sudbury River water-shed during the months from June to November, inclusive, was two and one-half times that during the corresponding months in 1880. A comparison by months from April to November is as follows:—

Yield of Sudbury River Water-shed in Gallons per Day per Square Mile.

MONTH.	1880.	1894.	MONTH.	1880.	1894.
April,	1,168,000	1,640,000	August,	119,000	209,000
May,	514,000	840,000	September,	80,000	150,000
June,	176,000	419,000	October,	101,000	374,000
July,	177,000	161,000	November,	205,000	836,000

reservoirs upon the Sudbury River, and the water in this lake therefore has an opportunity to become very much improved by bleaching and other changes which take place from long storage.

When the Sudbury water was first introduced into Boston, Lake Cochituate continued for several years to furnish by far the larger part of the water used, so that the higher color of the Sudbury water did not produce any great change in the color of the water supplied to the city; but the proportion of Sudbury water has been continually increasing, until at the present time about two-thirds of the supply comes from this source, and the water supplied to the city has a much higher color than formerly.

Both the Cochituate and the Sudbury water-sheds have a large population upon them for water-sheds used as sources of water supply. The population on the Cochituate water-shed at the present time is estimated to be 14,500, equal to 770 per square mile; and upon the Sudbury water-shed 28,300, equal to 376 per square mile. This makes the total population upon the two water-sheds 42,800, equal to 455 per square mile.

Much has already been done toward the protection of these waters from pollution by diverting sewage to points outside of the water-sheds. Sewerage systems for this purpose have already been constructed by Marlborough, Westborough and Framingham, the system at Framingham taking the sewage from the principal village, South Framingham, and from the Reformatory Prison for Women at Sherborn. The town of Natick is also preparing to divert its sewage to a point beyond the limits of these water-sheds. The sewerage systems already constructed and that to be built by Natick provide for a portion of the territory containing about 26,900 people, leaving a population in the villages without sewers and scattered about the water-sheds of 15,900, equal to 169 per square mile.

In addition to the diversion of the sewage, the city of Boston now pumps the water of Pegan Brook, which flows from the main village of Natick into Lake Cochituate, upon filter beds and purifies it by filtration before permitting it to flow into the lake. Plans for filtering in the same manner the water of a brook which flows from the city of Marlborough have been made and land has been acquired for this purpose.

By the construction of reservoirs carefully prepared for the reception of water by the removal of the soil and vegetable matter the city

has already improved to a considerable extent the quality of the Sudbury water, and a still further improvement will result from the additional storage to be provided by the large reservoir which is now being constructed. The city has also obtained authority from the Legislature (chapter 434 of the Acts of 1892) to drain swamps in Westborough and Hopkinton, and plans have been prepared for this work, but they have not yet been carried out. A consideration of this subject, together with an estimated cost of draining all of the swamps upon the Sudbury water-shed, is given in a report of Mr. Desmond FitzGerald, resident engineer of the additional water supply of the city of Boston, in Appendix No. 3. It will be feasible without excessive cost to divert still further and purify the sewage of the population upon the Sudbury water-shed.

The water from the Sudbury River as now supplied to the city of Boston is not nearly as good a water as it is desirable to supply to the metropolitan district; but it is capable of being improved by the methods already indicated, and will continue to be valuable as an auxiliary source of supply after a better supply is obtained from some new source. With the sewage of Natick diverted, the Cochituate water will be better than the Sudbury, and this source, if properly cared for, will probably continue to furnish a satisfactory water.

Future Supply. — It has already been stated that the construction of Reservoir No. 5 will not obviate the necessity for taking immediate steps to procure a still further supply of water for the territory now supplied by the city of Boston, or even for the territory now included within the city limits. The new reservoir will, however, develop the Sudbury system to such an extent that no further development will produce results commensurate with the expense,* so that the further supply will have to come from some new source.

While, from a financial standpoint, Boston may be amply able to obtain a new supply from almost any source which would be available to the metropolitan district, works for storing and conveying large quantities of water can be built so much more economically in

* In making this statement I have not taken into account a possible development of a small water-shed between the lowest permanent dam on the Sudbury River and the point at which the city took the waters of the river under the Sudbury River act, although it may be advisable to develop this territory so that it will furnish a portion, if not all, of the 1,500,000 gallons per day which the city of Boston is obliged to let flow down the Sudbury River below the point at which it took the water. The amount to be obtained from this development is so small that it does not materially affect the general statement above made.

proportion to the amount of water stored and conveyed than works upon a smaller scale, that it will undoubtedly be much cheaper for the city, as well as better for the other municipalities in the metropolitan district, that the city obtain its supply as a part of the district rather than independently.

Charlestown District of Boston, Somerville, Chelsea and Everett.

[Population in 1890, 117,477; estimated population in 1895, 141,941.]

Description and Capacity of Sources of Supply. — These places are supplied from the Upper Mystic Lake by works owned by the city of Boston. The total area of the water-shed of the lake is 27.75 square miles. The only storage under the control of the city of Boston is in the Upper Mystic Lake, which has been raised, by means of a dam, seven feet above the level of high tide in Boston harbor.

The capacity of this source was estimated in 1874 to be 7,000,000 gallons per day in a very dry year, and in 1883, a very dry year, when the average daily consumption of water from this source was a little less than 7,000,000 gallons per day, the lake was lowered to a level 7.89 feet below high-water mark, or, in other words, nearly to the level at which it would be necessary to pump the water from the lake into the aqueduct in order to maintain the supply, showing that the estimate made in 1874 was substantially correct.

There are ponds upon the Mystic water-shed not controlled by the city of Boston, and in an emergency water might be obtained from these ponds, adding somewhat to the capacity of this source; and there is the other method of adding somewhat to the estimated capacity, which has been adopted on several occasions; namely, of pumping water with auxiliary pumps from the lake into the aqueduct supplying the main pumps. During the past year, notwithstanding the fact already stated, that the year was not an extremely dry one, and that Charlestown was supplied for several months from the Cochituate Works, it was found necessary to pump from the lake until its level was lowered 12.08 feet below high-water mark, and 3.58 feet below the level at which a full supply will run by gravity through the aqueduct to the main pumps. If the year had been as dry as the year 1880, I estimate that it would have been necessary to draw the lake 20 feet lower than it has been drawn this year, in order to supply the quantity of water which has been used from the lake during

Cambridge.

[Population in 1890, 70,028; estimated population in 1895, 80,917.]

Description and Capacity of Sources of Supply. — The original source of supply of this city was Fresh Pond, which is located within the city limits. In 1887 an additional supply for the city was obtained from Stony Brook, which at the point of taking in Waltham is about 7½ miles from Fresh Pond. The water is conveyed from Stony Brook to Fresh Pond through an iron pipe 39,350 feet long, 5,010 feet of which is 36 inches in diameter and the remaining 34,340 feet 30 inches in diameter. The Stony Brook water-shed has an area of about 22.9 square miles, exclusive of the water-shed of Sandy Pond, which is at the extreme upper end of the brook, and from which practically all of the water which it will furnish in a dry year is used to supply the towns of Concord and Lincoln. At the point of taking, Stony Brook has been dammed, thereby creating a storage reservoir holding 354,000,000 gallons.

The water-shed of Fresh Pond is very small, and the amount of water which it will furnish has been reduced from time to time by the construction of sewers. It is now used as a receiving and storage reservoir from which to pump water for use in the city. Its storage capacity down to a point where a sufficient quantity of water will flow by gravity from it into the pump-well at the pumping station (8.35 feet below high-water mark) is 430,000,000 gallons, making the total storage capacity of the combined works 784,000,000 gallons. The capacity of the works in a very dry year is 7,200,000 gallons per day. By setting up a temporary pump at Fresh Pond and pumping into the conduit leading to the main pumps, as has been done at Mystic Lake during the past year and as was done at Cambridge in 1887, the pond might be drawn down to a level 15 feet below high-water mark, making available an additional storage of 285,000,000 gallons, and increasing the capacity of the sources in an emergency to 8,500,000 gallons per day. The capacity of the pipe leading from Stony Brook Reservoir to Fresh Pond, as given by the city engineer of Cambridge, is about 8,500,000 gallons per day.

Consumption of Water. — The average daily consumption of water in Cambridge during the past five years has been as follows: —

Consumption of Water, Cambridge.

YEAR.	Population supplied.*	Annual Increase (Per Cent).	Average Daily Consumption (Gallons).	Annual Increase.		Average Daily Consumption per Inhabitant (Gallons).
				Gallons.	Per Cent.	
1890, . . .	70,028		4,566,000			65
1891, . . .	73,640	5.2	4,857,000	291,000	6.4	66
1892, . . .	76,631	4.1	5,409,000	552,000	11.4	71
1893, . . .	79,469	3.7	6,181,000	772,000	14.3	78
1894, . . .	79,890	0.5	5,777,000	404,000†	6.5†	72

By reference to the above table it will be seen that the consumption of water has increased 1,211,000 gallons from 1890 to 1894; and if it should continue to increase at the same rate, the capacity of the present works in a dry year, without using an auxiliary pump at Fresh Pond, would be reached in 1899. These figures show that the consumption of water in Cambridge is approaching the full capacity of the present works.

Quality of Water. — Fresh Pond is situated in a thickly populated district, but its water has been protected from pollution to a considerable extent by taking a large area of land around its margins, and by constructing sewers to prevent the portion of the surface water from the populated portions of its water-shed from flowing into it. Some water which has once been polluted enters it by filtration through the ground, particularly when the pond is drawn to a low level.

When Fresh Pond derived its supply wholly from its own water-shed, — that is, before any water was turned into it from Stony Brook, — it contained a colorless water which had become hard owing to the wastes from the population upon the water-shed, which entered it mainly by percolation through the ground. These wastes, even if well purified by filtration, contained nitrogen in one form or another, which promoted the growth of the minute organisms found

* The populations given in this column do not include a small section of Somerville which is supplied with water from the Cambridge water works. All populations after 1890 are estimated.

† Decrease.

in water, and therefore caused, indirectly, disagreeable tastes and odors at times in the water of the pond. It seems probable that in the future, when the territory around Fresh Pond becomes still more densely populated than at present, it will be necessary, in order to prevent the pollution of the water, to provide sewers or drains all round the pond, to intercept surface water, and to keep the pond full so that there will be no underground flow into it.

The water of Stony Brook is soft, and contains considerable vegetable coloring matter derived from the swamps upon the water-shed in which the water stands or through which it passes. The storage reservoir at the lower end of the brook is not large enough to cause the water to bleach to any considerable extent. The estimated population upon the water-shed is 2,460, equal to 107 per square mile. The inhabitants upon the water-shed at the present time are largely engaged in farming and market gardening, although there is an increasing number of those who do business in the city of Boston who have summer homes upon it.

As more and more of the Stony Brook water is diverted into Fresh Pond with the increasing consumption of water in Cambridge, the water in the pond is changing in character and approaching more nearly that of the water of Stony Brook; and in time the quality of the water in the pond may be expected to become nearly the same as that of the water in the brook.

Future Supply. — The area of the Stony Brook water-shed is so large (22.9 square miles) that with sufficiently large storage reservoirs upon it a much larger quantity of water than at present might be obtained. The city of Cambridge has already taken the preliminary steps toward increasing the capacity of its works by appropriating money for the construction of a storage reservoir on Hobbs Brook, a branch of Stony Brook, by making surveys and estimates, and by acquiring land for this reservoir. The approximate area, capacity and cost of this reservoir, as given in the report of the Cambridge Water Board for 1893, are respectively 350 acres, 1,500,000,000 gallons and $600,000.* As a result of surveys made by the city of Cambridge since these estimates were made, it has been found advis-

* The letter of the city engineer of Cambridge, accompanying these estimates, states: "I have prepared an estimate of the probable expense of the proposed extension to the water supply system of the city. The estimates given are prepared from such data as I could procure in the limited time, and must be considered as approximate only."

able to locate the dam farther down Hobbs Brook than was originally intended, thereby forming a much larger reservoir. The area to be flowed by the dam in the new location is 653 acres, and the capacity of the basin is approximately 2,500,000,000 gallons. These figures will be modified somewhat, as the area will be decreased by the filling of shallow portions of the reservoir, and the capacity will be somewhat increased by the removal of soil.

The depth of water at the dam of the proposed reservoir is about 23 feet, and the average depth, disregarding the changes due to the removal of soil, 12 feet. At a point about half-way up the basin, where the depth of water is 14 feet, it is proposed to construct a second dam, which will not raise the water any higher than the main dam, but will permit it to be held at high-water mark while the water in the lower portion of the basin is being drawn down. Above this intermediate dam it is intended to remove the soil and vegetable matter, and to improve the reservoir by excavating and filling so that the water will have a minimum depth of 8 feet. Below the dam it is proposed to remove all of the soil from cultivated land and where the depth is less than 15 feet, but not to touch the flat meadow land in the bottom of the valley, where the peaty soil has considerable depth and its complete removal would be very costly. The area of the water-shed above the lower dam on Hobbs Brook, as measured from the State map, is 5.8 square miles, exclusive of the area of the reservoir.

The capacity of the Cambridge works after the construction of this reservoir and the addition of a second pipe of sufficient size from the Stony Brook Reservoir to Fresh Pond will be 13,200,000 gallons per day in the driest year, increasing the capacity of the works 6,000,000 gallons. Another reservoir of the same size as the Hobbs Brook reservoir would only increase the capacity of these works 3,000,000 gallons per day, and the cost would probably be too great in proportion to the results to be obtained to warrant the expenditure.

Lynn and Saugus.

[Population in 1890: Lynn, 55,727; Saugus, 3,673; total, 59,400. Estimated population in 1895: Lynn, 61,146; Saugus, 4,638; total, 65,784.]

Description and Capacity of Sources of Supply. — Both of these places are now supplied with water from works owned by the city of Lynn. Water was first introduced into Lynn in 1871, and for many years the supply was obtained from two artificial storage

reservoirs known as Breed's Pond and Birch Pond, which were built upon tributaries of the Saugus River; the former, in 1846, as a mill reservoir, and the latter in 1872. In 1884 an additional supply was obtained by taking two other tributaries of the river, known as Hawkes Brook and Penny Brook, and connecting them with the existing works. In order to still further increase the supply, two more artificial reservoirs, known as Glen Lewis Pond and Walden Pond, were built upon Penny Brook, and were filled for the first time in the latter part of 1889. The brush and wood were removed from these reservoirs, but the soil, mud and other vegetable matter were not removed; and as a consequence, although this water is free from sewage pollution, it has contained such abundant growths of minute organisms during a large portion of the time as to be wholly unsuitable for drinking.

In the latter part of 1893 the city exercised the authority granted it by the Legislature to take the water of Saugus River, and since then this water has been diverted from time to time either to the city or to the existing reservoirs.

The State Board of Health, in a communication to the Lynn Water Board, dated April 4, 1893, expressed the opinion that the Saugus River, at the point from which Lynn now takes a portion of its water supply, receives so much polluting matter from the towns of Wakefield and Reading as to render it an unfit source from which to take a water supply unless the water is very thoroughly purified by filtration.

It will therefore be seen that if the capacity of the Lynn sources is based upon the quantity of water which they will furnish, without regard to its quality, it will be much larger than if reckoned upon the basis of the amount of potable and wholesome water available.

After the addition of Hawkes and Penny brooks, but before the construction of Glen Lewis and Walden ponds, the capacity of the Lynn sources was about 2,950,000 gallons per day. After the construction of these reservoirs, but before the addition of the Saugus River, the capacity was about 3,450,000 gallons of water per day. The natural flow of the Saugus River added to the existing sources increases the capacity to about 8,000,000 gallons per day, provided the water is taken regardless of its quality; and if additional storage reservoirs can be built, or the present ones enlarged, a still larger quantity of water may be obtained.

Consumption of Water. — The average daily consumption of water in Lynn and Saugus during the past five years has been as follows: —

Consumption of Water, Lynn and Saugus.

YEAR.	Population.	Annual Increase (Per Cent.).	Average Daily Consumption (Gallons).	Annual Increase.		Average Daily Consumption per Inhabitant (Gallons).
				Gallons.	Per Cent.	
1890, . . .	59,400		2,657,000			45
		3.3		474,000	17.8	
1891, . . .	61,372		3,131,000			51
		5.2		418,000	13.3	
1892, . . .	64,570		3,549,000			55
		5.9		195,000	5.5	
1893, . . .	68,378		3,744,000			55
		4.8*		276,000	7.4	
1894, . . .	65,120		4,020,000			62

NOTE. — All populations after 1890 are estimated.
* Decrease.

It will be seen from this table that the consumption of water in Lynn and Saugus is already in excess of the safe capacity of the sources, exclusive of the Saugus River, in a dry year; and as the Saugus River, considered as a whole, should be excluded, it is obvious that Lynn and Saugus need an additional supply at the present time, but it may be feasible to obtain this supply from portions of the Saugus River water-shed.

Quality of Water. —There is only a very small population upon the water-sheds of the four reservoirs of the city of Lynn, and the city has acquired large tracts of land about them to protect them from pollution. It may therefore be said that if the Saugus River water were excluded the Lynn water would be very nearly free from any dangerous contamination. The waters have, however, the brownish color which water acquires from contact with vegetable matter in swamps and very shallow ponds; and, as already indicated, the water of Glen Lewis and Walden ponds contains such abundant growths of minute organisms during much of the time as to be wholly unsuitable for drinking. The water of Breed's Pond is generally better than that of Birch Pond.

The Saugus River at Howlett's Dam has a drainage area of 16.64 square miles, as determined by measurements from the topographical map of the State, and upon this area there is estimated to be a

population of 11,800, equal to 709 per square mile of drainage area. It is the large amount of polluting matter which enters the stream from the more densely populated portions of this district which makes the water of the Saugus River, as a whole, unsafe for drinking.

Future Supply. — The sources to which the city of Lynn would naturally look for an increase of its water supply are the Saugus and Ipswich rivers and their tributaries. I will consider first the possibilities of the Saugus River and its tributaries.

The water-shed of this river may, for the purpose of this consideration, be divided into several parts, as follows: —

	Area of Water-shed (Square Miles).
1. The Wakefield branch, exclusive of Crystal Lake,	3.08
2. Lake Quannapowitt and tributaries,	4.35
3. Beaver Dam Brook,	1.76
4. Pilling's Pond and tributaries,	2.05
5. The remaining area tributary to the main river above the dam of Howlett's Pond,	4.52
Total above Howlett's Dam, exclusive of Crystal Lake,	15.76
6. Central Brook,	3.00
Total, including Central Brook,	18.76

The reason for excluding the water-shed of Crystal Lake from the water-shed of the Wakefield branch is that the waters of this lake are now nearly all taken, and in the future will be wholly taken by the Wakefield Water Company. Upon the remaining 3.08 square miles of water-shed of the Wakefield branch there is a population of about 3,726, equal to 1,210 per square mile; and this population is increasing rapidly, so that it is obvious that the waters of this branch should not be used for water supply purposes.

Upon the 4.35 square miles of water-shed of Lake Quannapowitt are situated nearly the whole of the town of Reading and a portion of the town of Wakefield, making the total population about 5,854, equal to 1,346 per square mile. Regarding this lake, the State Board of Health advised the town of Reading, in March, 1889, that "the large population upon the water-shed of Lake Quannapowitt and the present quality of its water render it unfit for a domestic water

supply." On April 14, 1893, the State Board of Health advised the Wakefield Water Company that "it has already expressed and still holds the opinion that the water of Quannapowitt Lake, one of the sources named in your original act of incorporation, is now unfit for the purposes of a domestic water supply. This opinion as to the quality of Quannapowitt Lake water applies to taking water directly from the lake, but if the water was taken after it had been thoroughly purified by filtering for a long distance through the ground or by any other thorough method of filtration, it might be used." I certainly agree with the opinion that this is not a fit source from which to take water for drinking.

The 4.52 square miles of water-shed remaining tributary to the main river above Howlett's Dam, after excluding the other four areas given in the table, have very little population upon them; but this portion of the river receives the overflow of polluted water from Lake Quannapowitt at its upper end and toward its lower end the waters of the Wakefield branch. Even if these polluted waters were diverted, there still remains the objection to the utilization of this area, that there is along the river a very large area of wet swamp and meadow, probably as much as one square mile; and water flowing into this swampy area takes up so much vegetable matter in standing in and passing through it as to become unsuitable for water supply purposes, if not dangerous to health.

With the exclusion of these polluted waters and of the territory which contains such large swampy areas, there remains, above Howlett's Dam, only Pilling's Pond and its tributaries and Beaver Dam Brook, having together a water-shed of 3.81 square miles, to furnish a water supply.

Pilling's Pond is an artificial reservoir, formed many years ago by flooding a level meadow to a depth of four feet. Its area is about eighty-five acres, and its average depth is about three feet. Regarding this source the State Board of Health advised the Revere Water Company, in 1888, that "the water of Pilling's Pond, the proposed source of additional supply, when examined in October, 1888, was of fair quality; but, from the small depth of the pond, it will probably be unfit for use when drawn down two or three feet during the dry months, as it would be if used as a water supply for Revere and Winthrop." If this pond were raised, a very large additional area would be flooded to a small depth, and a reservoir would be formed which would be even less satisfactory than the present one. I do

not see how this source can be made a wholly satisfactory one for supplying water for Lynn and Saugus; although, as it is near Hawkes Brook, one of the present sources, it may prove valuable for furnishing, temporarily, an additional supply until a better water can be obtained.

Beaver Dam Brook is farther from Lynn than Pilling's Pond, and there is no pond or reservoir of any considerable size upon it at the present time. I am not fully informed as to whether or not it is feasible to build upon it a good storage reservoir.

If Pilling's Pond and Beaver Dam Brook were connected with the existing reservoirs by conduits of ample size, and there should be constructed on Hawkes Brook a reservoir, for which there is said to be a suitable site, the capacity of the Lynn works would be increased about 2,130,000 gallons per day, making a total capacity of 5,580,000 gallons.

The table already given shows that the consumption of water in Lynn increased from 2,657,000 gallons per day in 1890 to 4,020,000 gallons per day in 1894, making the average increase per year 341,000 gallons. With the same increase for each year after 1894, the capacity of the Lynn sources, with the addition of these two tributaries, would only provide a sufficient additional supply until the year 1899.

Central Brook is a tributary of Saugus River which takes its rise in the village of Greenwood in the southern part of the town of Wakefield, and enters the river from the west below Howlett's Dam. The Revere Water Company asked the advice of the State Board of Health with regard to this source in 1889, and the Board then replied that "Central Brook, on account of the population upon the water-shed and the character of the valley immediately adjoining the brook, will furnish a water of somewhat inferior quality, which will become worse with the growth of population, until before many years it will be unfit for water-supply purposes." Since this advice was given there has been a very rapid growth of population near the headwaters of this brook, and in my opinion it has become unfit for use for water-supply purposes.

All the foregoing statements have related to taking water directly from the streams and ponds. None of these waters, with the exception of the brook from Wakefield, are so much polluted but that if they were filtered a sufficient distance through the ground they

might become purified so as to be suitable for water-supply purposes.

There is a large area of sandy land in Wakefield, lying near the Saugus River, adjacent to the extensive swampy area already mentioned. With the view of ascertaining whether a ground-water supply, derived in part from the river by filtration, might be obtained at this place to supplement the present supply of Lynn and Saugus, I caused tests to be made by driving wells and pumping from them with a hand pump. The water so obtained was tested both by inspection and by analysis. There were in all fifteen of these wells, each two and one-half inches in diameter, and they were driven to depths ranging from seventeen to sixty-two feet and averaging thirty-seven feet below the surface. Eight of the wells were driven until they reached ledge. The material penetrated was for the most part a moderately fine sand, from which water could not be pumped freely with a pipe having an open end, because as soon as the pumping was begun the sand would run in and fill the pipe; but by using a strainer at the end of the pipe, better results were obtained, and at most of the points where tests were made there is little doubt but that a moderate quantity of water might be obtained from driven wells by using strainers adapted to taking water from the material penetrated.

Chemical analyses were made of the water from eight of the wells, and in most cases it was found to be of good quality, while in the others the water either contained enough iron to make it somewhat objectionable for laundry purposes, or to lead to the expectation that it might become unsuitable if water were pumped regularly from the locality in which these wells were driven. The territory covered by these tests was very irregular in shape, as arms of the swamp in several places extended into the sandy and gravelly land, cutting it into islands and peninsulas. The greatest distance between extreme borings in one direction was about 4,100 feet, and in the other about 3,000 feet. It was thought that if water were to be pumped from the ground at this place it would be necessary to throw dams across some of the arms of the swamp, so that the river water would not run into them and injure the quality of the ground water by filtering down through the mud.

With the river water shut out in this way, it is thought that a system of driven wells extending over most of the area tested might

furnish 1,000,000 gallons of water per day, but would not be likely to furnish more than this amount. As this quantity of water would only provide for about three years' increase in the consumption of water in Lynn and Saugus at the rate at which the consumption increased from 1890 to 1894, and the works would be quite costly in proportion to the amount of water obtainable, this does not seem to be a desirable plan for increasing the water supply of these places.

It is not improbable that a somewhat larger quantity of good water could be obtained from the ground at this place if it were kept saturated by pumping water from the Saugus River upon the sandy areas in the vicinity of the wells and filtering it intermittently into the ground. This method has already been referred to on page 13 of this report; but owing to the fineness of the sand, which would interfere to some extent with the filtration of the water into the ground and through the ground in the vicinity of wells, and the possible difficulty of satisfactorily filtering a water which has such a high color and contains so much organic matter as that of the Saugus River, it was thought that this place was an unfavorable one for adopting this experimental method of purifying water.

I have also considered the question of filtering the water of this river through artificial filters; but I should not advise the adoption of this plan if good water could be obtained in other ways.

The other source of supply mentioned, namely, the Ipswich River, is the nearest available source other than the Saugus River which will furnish any large quantity of water for Lynn. This river does not have a very large population upon its water-shed, but it is polluted to such an extent that it cannot be regarded as a safe source from which to take a water supply unless the water is subsequently filtered or stored for a considerable time. Moreover, there are so many swamps on the water-shed that its water has more color than that of any other source examined during the investigations for a metropolitan water supply, so that, even if the stream were entirely free from artificial pollution, its water would not be of satisfactory quality for domestic use without purification.

It was thought possible that a good ground-water supply might be obtained from the valley of this river; but a superficial examination of the valley indicated that it was very doubtful if this would be the case, and, even if a good ground-water supply could be obtained, it would

probably cost more than water from the proposed metropolitan system.

In addition to the foregoing sources the Lynn authorities have recently called my attention to Cedar Brook, a tributary of Sluice Pond, in the northerly part of Lynn, as a further available source of supply, with a water-shed of 1.2 square miles. If the water of this source should prove to be of good quality the increase in the supply by adding it would be equal to the increase in consumption for two years at the rate at which the consumption increased from 1890 to 1894. There is an objection to taking the water of this brook permanently because it is the main feeder of two large ponds in Lynn on the borders of which there is a large population, and the water of the brook is an important factor in maintaining the water of these ponds in proper sanitary condition.

Newton.

[Population in 1890, 24,379; estimated population in 1895, 28,470.]

Description and Capacity of Sources of Supply. — This city obtains its supply of water from the ground near the Charles River in the town of Needham. When the works were first completed in 1876 the supply was taken from an open filter basin 1,575 feet long. In 1890 the collecting system was extended along the river, making the total length 3,795 feet. When this extension was completed it was estimated that the works would furnish 2,000,000 gallons per day in the driest months of the year. In 1894 the consumption of water had so nearly reached the capacity of the works that it became necessary to make a farther extension of the collecting system up the river, and the total length of this system is now about 7,050 feet. The whole of this system is now a covered filter gallery or conduit, made in part of wood and in part of vitrified clay pipe; and connected with this conduit at intervals are many driven wells, extending down into the more porous strata which are found at a considerable depth.

A portion of the water comes to the filter gallery from the land side, but a large part of the supply is water which has filtered into the ground from the river. The capacity of the source is therefore largely dependent upon the amount of water which can get into the ground from the river either by filtration through meadows and the bottoms of ditches when the river overflows its banks in the spring, or by filtration through the river bottom and sloping banks

in the vicinity of the collecting system. The amount of water stored in the interstices of the porous ground in the spring of the year when the river is high is also an important factor, as this storage furnishes a reserve which can be drawn upon in the summer, when there is a diminished amount of water coming from the land side and filtering from the river into the ground. It is estimated that the works as now constructed will furnish 2,300,000 gallons of water per day in the driest portions of the year; but, as the consumption of water at such times is higher than the average for the whole year, the capacity of the works in a very dry year is likely to be reached by an average daily consumption throughout the year of about 2,000,000 gallons per day.

Consumption of Water. — The average daily consumption of water in Newton during the past five years has been as follows: —

Consumption of Water, Newton.

YEAR.	Population.	Annual Increase (Per Cent.).	Average Daily Consumption (Gallons).	Annual Increase.		Average Daily Consumption per Inhabitant (Gallons).	Average Daily Consumption, June to October, Inclusive.	
				Gallons.	Per Cent.		Gallons.	Gallons per Inhabitant.
1890, .	24,379		985,000			40	1,115,000	46
		4.2		80,000	8.1			
1891, .	25,400		1,065,000			42	1,181,000	46
		4.1		223,000	20.9			
1892, .	26,450		1,288,000			49	1,445,000	55
		4.0		82,000	6.0			
1893, .	27,500		1,370,000			50	1,525,000	55
		2.3		253,000	18.5			
1894,* .	28,144		1,623,000			58	1,921,000	68

NOTE. — All populations after 1890 are estimated.

* Since May 1, 1894, an additional amount of about 350,000 gallons of water per day has been supplied for manufacturing purposes.

This table shows that the consumption of water during the months from June to October, inclusive, has increased from 1,115,000 gallons per day in 1890 to 1,571,000 gallons per day in 1894, exclusive of the 350,000 gallons per day supplied for manufacturing purposes, making the annual increase 114,000 gallons. If the increase were to continue at the same rate in the future, the estimated capacity of the works with their present development would be reached in 1897; or if the city were to cease supplying the 350,000 gallons per day for manufacturing purposes, the present works would maintain the supply until 1900, when it would be nec-

essary to still farther extend the present works or otherwise obtain an additional supply.

Quality of Water. — The water obtained from the Newton works is of excellent quality, and, as it is kept from exposure to the light both before and after it is pumped, it is a very satisfactory water when delivered to the consumers. The water has been analyzed frequently by the State Board of Health for many years, and the analyses do not indicate that it is deteriorating. There is, however, the possibility already referred to on page 10 of this report, that any filtered river water may in time become of unsatisfactory quality.

Future Supply. — The city of Newton has already taken the land along the Needham bank of the Charles River from a point a short distance below the end of its present works to the boundary line between Needham and Dedham, a total length of about 15,500 feet. It has also taken land on the opposite or Newton side of the river, extending northerly from the Boston line, for a length of about 7,500 feet. This land was taken with a view to developing the supply by extending through it collecting galleries or pipes, similar to those already constructed, in which the water can be drawn down until it is about six feet below the normal level of the water in the river. It is estimated that a system of this kind can be made to supply 5,000,000 gallons of water per day during the driest portion of the year, and that this quantity of water will be sufficient for the requirements of the city of Newton until about the year 1908, at which time it is estimated that the city will have a population of about 51,000. The city now has authority to take from the river 5,000,000 gallons of water daily.

Malden.

[Population in 1890, 23,031; estimated population in 1895, 30,240.]

Description and Capacity of Sources of Supply. — This city is supplied from two sources, — Spot Pond, which is used jointly with Medford and Melrose, each municipality being entitled to one-third of its water, and wells in the vicinity of Maplewood, in the easterly part of the city, which furnish a ground-water supply.

Spot Pond when full has an area of 296 acres; a water-shed of 1,296 acres, including the area of the pond; a storage capacity of 733,000,000 gallons down to a level 12 feet below high water, which is about the lowest level to which the pond has ever been drawn, and a capacity of 837,000,000 gallons when drawn to a level of 15 feet below high water. In a series of dry years such as have

occurred in the past, it is feasible, by utilizing the storage in the first 12 feet of depth, to draw from the pond 1,560,000 gallons per day and have the pond fill up again. Malden's share of water from this source may therefore be reckoned at 520,000 gallons per day.

The Maplewood supply is obtained from a group of about 99 tubular wells, about half of which were driven in 1889 and the remainder in 1892 and 1894. These wells yielded an average of 1,205,000 gallons of water per day in 1894. In reckoning the capacity of the wells, it is not necessary to base it upon the amount of water which they will furnish in the driest year, because in such a year the large amount of water stored in Spot Pond could be drawn upon to prevent a deficiency in the supply. It does not seem probable, however, that they can be depended upon in a series of dry years, such as have occurred in the past, to furnish over 1,000,000 gallons of water per day; and this quantity may be reduced, as sewers are introduced into the district which will carry off a portion of the ground water and also divert that portion of the water supplied to this district which, after being used, is now turned into the ground through cesspools.

The total capacity of both sources of supply may be reckoned at about 1,520,000 gallons per day.

Consumption of Water. — It is only since a meter was placed on the main pipe in September, 1892, to measure the quantity of water drawn from Spot Pond, that the consumption of water by the city could be accurately obtained. The following table therefore contains only the record of consumption for the past three years, and the record for 1892 covers only the last four months of the year: —

Consumption of Water, Malden.

YEAR.	Population.	Annual Increase (Per Cent.).	Average Daily Consumption (Gallons).	Annual Increase.		Average Daily Consumption per Inhabitant (Gallons).
				Gallons.	Per Cent.	
1892, . . .	26,435		1,243,000			47
		6.9		107,000	8.0	
1893, . . .	28,253		1,451,000			51
		4.2		9,000,000	0.6	
1894, . . .	29,452		1,460,000			41

NOTE.— All populations are estimated.

It will be seen that the consumption of water is already very nearly equal to the capacity of the combined sources in a series of

dry years. If, however, Spot Pond should be filled in the spring of 1895 or 1896, it would for the next two or three years furnish without becoming exhausted a much larger quantity of water than it can be depended upon to furnish in a long series of years.

Quality of Water. — Spot Pond has generally furnished water of satisfactory quality, but during the last two or three years, when the pond has been drawn to a very low level, the water has not been quite as good. The population upon the water-shed is about 476, equal to 305 per square mile of land surface. The water has been affected at times by disagreeable tastes and odors, due to the presence of microscopic organisms, but these troubles have only occurred after long intervals. Much land has been taken around the pond by the three municipalities controlling it, to protect it from pollution; and the Metropolitan Park Commission has acquired a considerable portion of the water-shed as a part of the Middlesex Fells reservation.

The water from the Maplewood wells contains a very large and increasing amount of mineral matter, and it is very hard, these characteristics being due to the presence of a very large population on the territory from which the supply of these wells is derived; but the analysis also shows a very thorough purification of the water, owing to its filtration through the ground, and that it is practically free from organic matter.

Future Supply.—The city of Malden has been authorized by the Legislature to take water from Martin's Pond in North Reading, and it has made investigations relative to taking a water supply from this source. The pond in its present condition will not furnish a satisfactory water supply, and it does not seem probable that it can be improved in such a way as to make it furnish a good water except at a prohibitory expense. Investigations have also been made by the city of Malden to determine the feasibility of obtaining a supply of water from the ground in the vicinity of the pond, but I am informed that the results are unfavorable to obtaining a supply in this way. The distance from Malden to Martin's Pond is about twelve miles, and the water would have to be supplied by pumping, so that the cost of the works and of their maintenance would be large.

Waltham.

[Population in 1890, 18,707; estimated population in 1895, 21,700.]

Description and Capacity of Source of Supply. — This city from 1873 to 1891 obtained its supply of water from a filter basin having

an area of a little less than one-fourth of an acre, dug in gravelly land close to the westerly side of the great millpond of the Boston Manufacturing Company on the Charles River. This filter basin had a depth of 8.4 feet below the water level in the river. In 1891, when the average consumption of water during the five months from June to October, inclusive, was 858,000 per day, a well 40 feet in diameter was sunk in the middle of the basin to an additional depth of 18 feet, and in 1893 the well was covered so as to prevent the growth of certain low forms of vegetation which injured the quality of the water.

Very large quantities of water were pumped from this well during its construction, and it does not seem improbable that it will furnish from 3,000,000 to 3,500,000 gallons per day in the driest times. The location of the well is very favorable for obtaining a large supply of water, as the porous, gravelly land in which it was dug extends for a long distance on both sides of the river, and the millpond is broad and has arms extending up into the gravelly land, so that there is a very large area of millpond bottom through which water can filter from the river into the ground; and there is little doubt but that a considerable portion of the water supplied by this well now comes from the river, and that a still larger porportion will be obtained in this way in the future.

Consumption of Water. — The average daily consumption of water in Waltham for the past five years has been as follows: —

Consumption of Water, Waltham.

YEAR.	Population.	Annual Increase (Per Cent.).	Average Daily Consumption (Gallons).	Annual Increase. Gallons.	Annual Increase. Per Cent.	Average Daily Consumption per Inhabitant (Gallons).	Average Daily Consumption, June to October, Inclusive. Gallons.	Average Daily Consumption, June to October, Inclusive. Gallons per Inhabitant.
1890, .	18,707		626,000			33	705,000	38
		9.1		143,000	22.8			
1891, .	20,400		769,000			38	858,000	42
		4.7		150,000	19.5			
1892, .	21,350		919,000			43	1,026,000	48
		1.2		136,000	14.8			
1893, .	21,600		1,055,000			49	1,199,000	56
		2.3*		182,000	17.3			
1894, .	21,100		1,237,000			59	1,385,000	66

NOTE. — All populations after 1890 are estimated. * Decrease.

Quality of Water. — The water as it now comes from the well is of excellent quality, but some of it on its way to the city passes through an open distributing reservoir in which there are abundant

growths of microscopic organisms, so that the water is not delivered to the consumers in as good condition as it comes from the ground.

There are two possible causes of future deterioration of the water coming from the well. The first is the possibility already referred to on page 10 of this report, that any filtered river water may in time become of unsatisfactory quality; but with regard to this it may be said that the works have now been in use for twenty-one years, and the analyses do not show any signs of deterioration from this cause. The second is the danger from polluting matters turned into the ground in the territory from which the well derives its supply. The water comes to the well from the ground on both sides of the river, and on the side across the river from the well the land has been divided into lots, and many buildings have been constructed from which the wastes are run into cesspools. Pollution of the ground water in this way can be prevented by providing an efficient system of sewers for removing the polluting wastes.

Future Supply. — The city of Waltham has acquired land along the banks of Charles River for a distance of about 1,700 feet up stream from the pumping station, and for an average depth back from the river of about 1,200 feet. Owing to the many irregularities of the shore line, its total length is about 4,600 feet. It was thought desirable to ascertain from how great a distance the present well drew its supply, both to assist in determining the present capacity of the well, and in finding out whether there was gravelly territory in addition to that from which the well drew its supply from which an additional supply might be obtained. For this purpose the height of the ground water was determined at many points on both sides of the river by ascertaining the level of the water in wells, test pits and small ponds, these determinations extending to a distance of as much as a mile from the pumping station in some directions.

After the levels were first taken the fluctuations in the height of the water in these wells, test pits and ponds was observed from time to time. From these observations it was concluded that the present well when pumped to a low level would draw water from a very long distance, but not from the whole area which might be available for furnishing a ground water supply; and it was therefore thought probable that an additional well or wells might be sunk at a considerable distance from the present well, that would increase the capacity of the works to 5,000,000 gallons of water

per day during the driest portion of the year. This quantity of water should be sufficient for the requirements of the city until about the year 1920.

At the present time the city is authorized to take from the Charles River or from the ground near it not more than 3,000,000 gallons of water daily.

Quincy.

[Population in 1890, 16,723; estimated population in 1895, 22,140.]

Description and Capacity of Sources of Supply. — This city was first supplied with water from two wells constructed in 1884, but its main source of supply is now a storage reservoir on Town Brook in Braintree, which was first filled in 1888, and only one of the wells is now used. The storage reservoir when full has an area of 45 acres, a water-shed of 991 acres including the reservoir, and a storage capacity of about 167,000,000 gallons.

After making allowance for considerable leakage past the dam and through the gravelly land at one side of the reservoir, this source will supply 750,000 gallons of water per day in the driest year, and the well will yield about 90,000 gallons per day, making the total daily capacity of the present sources 840,000 gallons.

Consumption of Water. — The average daily consumption of water in Quincy for the past five years is given in the following table: —

Consumption of Water, Quincy.

YEAR.	Population.	Annual Increase (Per Cent.).	Average Daily Consumption (Gallons).	Annual Increase.		Average Daily Consumption per Inhabitant (Gallons).
				Gallons.	Per Cent.	
1890, . . .	16,723		497,000			30
		6.9		68,000	13.7	
1891, . . .	17,880		565,000			32
		6.3		37,000	6.6	
1892, . . .	19,000		602,000			32
		5.8		127,000	21.1	
1893, . . .	20,100		729,000			36
		5.4		69,000	9.5	
1894, . . .	21,194		798,000			38

NOTE. — All populations after 1890 are estimated.

It will be seen from this table that the consumption of water in 1894 very nearly equalled the capacity of the sources in a very dry year, and an additional supply is now required.

Quality of Water. — The water-shed from which the reservoir derives its supply contains much swampy land, which gives the water a brownish color, and there are some piggeries upon it which are objectionable features. The reservoir was filled without removing the soil and mud from the land flowed, and the water is affected to a considerable extent by growths of the minute organisms often found in reservoirs, which give the water at times a disagreeable taste and odor. The quality of the water has shown a slight tendency to improve during the past two or three years, but it cannot in its present condition be regarded as a satisfactory water for the purposes of a public water supply. There is very little doubt, however, but that the quality of the water may be greatly improved by removing the piggeries from the water-shed, by draining the swamps and by removing the soil and mud from the bottom of the reservoir. The water-shed contains only a comparatively small population.

Future Supply. — Outlines of a plan for increasing the water supply of this city have recently been submitted to the State Board of Health for its advice by the mayor and water board. The plan suggested is the construction of another storage reservoir upon a small brook very near the existing reservoir, and the diversion into the existing and proposed reservoirs of the water of Blue Hill River. The city officials were advised that this plan would probably increase the supply so that it would in the driest year meet the requirements of the city until the year 1905, and that, if it were feasible to build a large reservoir above the Taunton turnpike, referred to in a report published by the city of Quincy in 1890, the supply might be increased sufficiently to last until about the year 1921. The cost of the works for supplying a water of good quality from these sources would be large.

There is no source, other than the Blue Hill River, within a reasonable distance of Quincy, from which any large additional supply of water of good quality could be obtained, which is not already controlled by other cities and towns.

Hyde Park and Milton.

[Population in 1890: Hyde Park, 10,193; Milton, 4,278; total, 14,471. Estimated population in 1895: Hyde Park, 12,300; Milton, 5,800; total, 18,100.]

Description and Capacity of Source of Supply. — The Hyde Park Water Company supplies water to the town of Hyde Park and to the Milton Water Company, and the latter company supplies the water purchased from the Hyde Park Water Company to the town of Milton. The whole water supply is derived from wells located

near the Neponset River, only a short distance above the thickly settled portion of Hyde Park. Additional wells were driven to increase the capacity of this source in 1893 and 1894, but it is very doubtful if the works as extended will furnish in a very dry season any more good water than is needed to supply the present demands. Water was first introduced into Milton in 1890.

Consumption of Water. — The consumption of water in Hyde Park and Milton for the past five years is given in the following table: —

Consumption of Water, Hyde Park and Milton.

YEAR.	Population.	Annual Increase (Per Cent.).	Average Daily Consumption (Gallons).	Annual Increase.		Average Daily Consumption per Inhabitant (Gallons).	Average Daily Consumption for Maximum Two Months in Summer.	
				Gallons.	Per Cent.		Gallons.	Gallons per Inhabitant.
1890, .	14,471		391,000			27	465,000	32
1891, .	15,240	5.3	498,000	107,000	27.4	33	613,000	40
1892, .	16,020	5.1	564,000	66,000	13.3	35	678,000	42
1893, .	16,720	4.4	628,000	64,000	11.4	38	727,000	43
1894, .	17,469	4.5	587,000	41,000*	6.5*	34	713,000	41

The consumption of water in each town for the past three years is as follows: —

Consumption of Water, Hyde Park.

YEAR.	Population.	Annual Increase (Per Cent.).	Average Daily Consumption (Gallons).	Annual Increase.		Average Daily Consumption per Inhabitant (Gallons).
				Gallons.	Per Cent.	
1892, . .	11,100		464,000			42
1893, . .	11,500	3.6	499,000	35,000	7.5	43
1894, . .	11,948	3.9	458,000	41,000*	8.2*	38

Consumption of Water, Milton.

1892, . .	4,920		100,000			20
1893, . .	5,220	6.1	129,000	29,000	29.0	25
1894, . .	5,521	5.8	129,000	0	0	23

NOTE. — All populations after 1890 are estimated. * Decrease.

Quality of Water. — A portion of the water furnished by the wells of the Hyde Park Water Company is derived from rain which falls upon the land on both sides of the river at no very great distance from the wells, but it is probable that most of the water comes by filtration from the Neponset River, which is a highly polluted stream.

Analyses of water from many of the wells and groups of wells controlled by the company show that some of them furnish water which is not perfectly purified by filtration, while others furnish or have furnished water that is or was very thoroughly purified. The fact that a well furnishes good water at one time does not prove that it will continue to do so for an unlimited period, as the purifying powers of the soil may become exhausted. On the whole, it may be said, regarding the quality of the water from these wells, that while some of them furnish good water, — and possibly enough of them to provide such water for the present supply of Hyde Park and Milton, — yet it is doubtful if both these places can be supplied without drawing from the territory which furnishes water that is not efficiently purified.

Taking into account the high degree of pollution of the river, the inefficiency of the purification by filtration in a portion of the territory and the tendency which the ground has to lose its purifying power with continued use, I believe that this source of supply will always be regarded with suspicion, and that it should be abandoned when a better supply can be obtained.

Future Supply. — There is apparently no available source within a reasonable distance of the present one which will furnish a sufficient amount of water of good quality for Hyde Park and Milton. The Milton Water Company, however, has made investigations with reference to obtaining a supply of ground water from low land in the town of Milton, on the east side of Harland Street and near Pine Tree Brook, and was advised by the State Board of Health that a sufficient supply of ground water to meet the requirements of the town for a few years, and possibly for a much longer time, could probably be obtained at this place. If the Milton Water Company should obtain this supply, the Hyde Park Water Company, having only the town of Hyde Park to provide for, could furnish a better water than it can supply to both towns; and the Milton Water Company might obtain enough water to temporarily supply a portion of the water consumed in Hyde Park. There seems to be no source, other than the one in the town of Milton, from which the Milton Water Company can obtain an independent supply of good water at a reasonable cost.

Woburn.

[Population in 1890, 13,499; estimated population in 1895, 14,701.]

Description and Capacity of Source of Supply. — This city obtains its supply from a filter gallery constructed in 1873 near the

southerly shore of Horn Pond, — a pond which is seriously polluted, owing to the presence upon its water-shed of a large population and of tanneries and other manufacturing establishments which produce offensive wastes. The salt used in the tanneries and discharged into the streams with the tannery wastes, and that contained in the other wastes which enter the pond, has increased the chlorine in the water to many times its normal amount; and the water of the filter gallery contains nearly as much chlorine as that of the pond, furnishing conclusive evidence that the water filters from the pond to the gallery. It is estimated, from analyses which have been made monthly for seven years, that about ninety-two per cent. of the water which entered the filter gallery during that time came by filtration from the pond.

The supply furnished by the filter gallery has been sufficient for the needs of the city from the first, but in 1882, when the consumption of water in July and August averaged 1,056,000 gallons per day, it threatened for a time to prove too small. Measures were then taken to hold the surface of the pond at a higher level, and during the very dry year of 1883 and every year since that time the supply has been sufficient for all purposes. It should be added, however, that the consumption of water in 1883 was less than in 1882, the average amount during the month of highest consumption being 911,000 gallons per day, and the average for the three months from July to September being 832,000 gallons per day.

Consumption of Water. — The consumption of water in Woburn for the past five years has been as follows: —

Consumption of Water, Woburn.

YEAR.	Population.	Annual Increase (Per Cent.).	Average Daily Consumption (Gallons).	Annual Increase.		Average Daily Consumption per Inhabitant (Gallons).	Average Daily Consumption for Maximum Two Months in Summer.	
				Gallons.	Per Cent.		Gallons.	Gallons per Inhabitant.
1890, .	13,499		777,000			51	969,000	72
1891, .	13,760	1.9	730,000	47,000*	6.1*	53	801,000	58
1892, .	13,990	1.7	775,000	45,000	6.2	55	956,000	68
1893, .	14,220	1.6	900,000	125,000	16.1	63	1,161,000	82
1894, .	14,460	1.7	972,000	72,000	8.0	67	1,295,000	90

* Decrease.

It will be seen, by comparing the consumption during the two months in summer, as given in the table, with the summer consumption in 1882 and 1883, as previously given, that there had been practically no increase up to 1892, — a result which is supposed to be due to a large loss by leakage from the reservoir and the distributing system in the earlier years, which has been greatly reduced in recent years. The increase in consumption in 1893 and 1894, however, seems to show an increasing demand for water. The indications are that the consumption of water has already reached the capacity of the present source in a dry year, and that measures should be taken for increasing the supply.

Quality of Water. — It has already been stated that the filter gallery receives the greater part of its water by filtration from Horn Pond, and that this pond is seriously polluted. Analyses of the water of the filter gallery which have been made monthly for the past seven years show that the character of the water is entirely changed by filtration, the organic matter being reduced to a very small amount and the water being rendered suitable for drinking. During the past two years the amount of free ammonia in the water of the filter gallery has been slightly larger than in previous years, which is an indication that the purification is becoming less perfect; but the change has been so slight up to the present time that it cannot be regarded as more than an indication. It is essential, where water is derived by filtration from a polluted source, that the purification should be very nearly perfect, as the water otherwise becomes unsafe for drinking.

There have been at times in the past complaints of bad tastes and odors in the water supplied to Woburn, but it is believed that these were caused by vegetable growths in the open distributing reservoir, rather than by the imperfect purification of the water entering the filter gallery.

Future Supply. — It may be possible, by the construction of another filter gallery or well in porous ground near the pond, and at a considerable distance from the present filter gallery, to obtain a further supply of filtered water, or it may be feasible to facilitate the filtration of the pond water into the present filter gallery in such a way as not to diminish the purity of the water. If these methods should fail, the city of Woburn may take advantage of its nearness to territory which is only sparsely populated to obtain a supply of surface water by the construction of a storage reservoir upon some

unpolluted stream. The population on the water-shed of Horn Pond is so large (975 per square mile) that it cannot be regarded as a safe source from which to take a water supply directly, even after a system of sewers has been constructed in Woburn.

Wakefield and Stoneham.

[Population in 1890: Wakefield, 6,982; Stoneham, 6,155; total, 13,137. Estimated population in 1895: Wakefield, 8,119; Stoneham, 7,072; total, 15,191.]

Description and Capacity of Source of Supply. — These towns are supplied by the Wakefield Water Company with water from Crystal Lake in Wakefield. The lake when full has an area of 85 acres, and a water-shed, including the area of the pond, of .94 of a square mile. A portion of the lake covering about 30 acres is very shallow. The capacity of this source in a series of dry years, such as has occurred in the past, is about 660,000 gallons per day.

Consumption of Water. — The consumption of water in Wakefield and Stoneham for the four years, from 1890 to 1893, inclusive, is given in the following table: —

Consumption of Water, Wakefield and Stoneham.

YEAR.	Population.	Annual Increase (Per Cent.).	Average Daily Consumption (Gallons).	ANNUAL INCREASE.		Average Daily Consumption per Inhabitant (Gallons).
				Gallons.	Per Cent.	
1890, . . .	13,137		537,000			41
		3.3		4,000	0.7	
1891, . . .	13,570		541,000			40
		3.8		58,000	10.7	
1892, . . .	14,080		599,000			43
		3.2		46,000*	7.7*	
1893, . . .	14,528		533,000			38

NOTE. — All populations after 1890 are estimated.
* Decrease.

The consumption of water for 1894 is not given in the above table because the water company refused to furnish it. There is but little doubt, however, that the consumption during this year has been greater than in either 1892 or 1893, because the pond at the end of 1894 was lower than at the end of the other years mentioned; and, judging from the yield of other sources in the eastern part of Massachusetts, the amount of water entering the pond from its water-shed, from the time it stopped overflowing in the spring of 1894

until the end of the year, was as great as during the corresponding period in either 1892 or 1893. The consumption of water in 1892 was only a very little less than the estimated capacity of this source in a series of dry years, and the consumption in 1894 probably equalled, if it did not exceed, this capacity.

Quality of Water.—Crystal Lake furnishes a nearly colorless water, which has generally been of satisfactory quality, though it has been affected on a few occasions by the presence of the minute organisms which impart to the waters of many ponds and reservoirs a disagreeable taste and odor. The water-shed contains at the present time a population of about 335, equal to 356 to the square mile. This is a large population, and on account of the proximity of the water-shed to the thickly settled parts of Stoneham and Wakefield it is likely to increase rapidly in the future.

Future Supply. — In addition to Crystal Lake, the Wakefield Water Company was authorized by the Legislature to take water from Quannapowitt Lake in the town of Wakefield. This lake has a water-shed of 4.35 square miles, including its own area, and upon this water-shed there is estimated to be, in the towns of Reading and Wakefield, a population of 5,854, equal to 1,346 per square mile; moreover, there are extensive swamps upon the water-shed, which unfavorably affect the character of the water and render it less attractive than the water of Crystal Lake.

The State Board of Health advised the Wakefield Water Company, on April 14, 1893, that "it has already expressed and still holds the opinion that the water of Quannapowitt Lake, one of the sources named in your original act of incorporation, is now unfit for the purposes of a domestic water supply. This opinion as to the quality of Quannapowitt Lake water applies to taking water directly from the lake; but if the water were taken after it had been thoroughly purified by filtering for a long distance through the ground, or by any other thorough method of filtration, it might be used." *

I have caused two test wells to be driven, one near the northerly end of this lake and another on the northerly side of its outlet, at points where it seemed most probable from surface indications that a ground-water supply, derived mainly from the lake or its outlet by filtration, might be obtained.

The well near the northerly end of the lake was driven through moderately coarse sand, from which water could be pumped quite

* Annual Report of State Board of Health for the year 1893, page 58.

freely, to a depth of 31 feet, and was then driven 50 feet further through much finer sand which did not furnish water freely. A sample of water taken from this well at a depth of 81 feet was analyzed, and was found to contain much iron, to be hard, and to have some other unfavorable characteristics which would make it undesirable for water-supply purposes.

The well driven north of the outlet of the lake reached ledge 28 feet below the surface, but passed most of the way through porous gravel and sand from which water could be pumped freely. The analysis of a sample taken from this well showed that the water was of much better quality than the water from the well at the end of the lake. The analysis had some unfavorable features, however, and it would require further examinations to determine whether a water of suitable quality for water-supply purposes could be obtained at this place or not. The nearness of the ledge to the surface and the comparatively short distance from the well to ground which is nearly impervious render it very doubtful if any large supply of water could be drawn continuously from the ground near this well.

On the whole it may be said, with regard to these tests, that, while they were not carried far enough to enable definite conclusions to be drawn, they indicate that it would be difficult if not impracticable to obtain a satisfactory ground-water supply from either of the localities tested.

In the town of Wakefield, north of Lowell Street and near the Saugus River, there is a large area of sandy land from which it seems probable that a ground-water supply sufficient for the needs of Wakefield and Stoneham for the next ten or fifteen years, and possibly for a longer time, might be obtained. This area has been tested by means of driven wells, and the results are given on pages 31 and 32 of this report; but, as this area is within the territory from which the city of Lynn was authorized to take water by the Legislature of 1893, it is not probable that it can be made available for the water supply of Wakefield and Stoneham; and if it were available, it may be questioned whether, after taking into account the first cost and maintenance of a pumping station, wells and other works for obtaining a supply from this place, together with the uncertainties regarding the amount of water which may be obtained from a ground-water source, it would not be cheaper to obtain the additional supply for Wakefield and Stoneham from the metropolitan system.


The portions of this map printed in red relate to works proposed by the State Board of Health for the water supply of the Metropolitan District.
Figures show elevations of full reservoirs and of bottoms of aqueducts in feet above Boston Water Works base.
BOSTON WATER WORKS
WATER-SHEDS OF THE SUDBURY AND COCHITUATE SUPPLIES
1894
DESMOND FITZGERALD
RES^T ENG^R & SUP^T
SCALE
HUDSON
BERLIN
SOUTH BERLIN
MARLBOROUGH
NORTHBOROUGH
SOUTHBOROUGH
FAYVILLE
WAYLAND
SAXONVILLE
COCHITUATE
NOBSCOT
FRAMINGHAM
SOUTH FRAMINGHAM
FELCHVILLE
NATICK
SOUTHVILLE
CORDAVILLE
WESTBOROUGH
ASHLAND
WOODVILLE
HOPKINTON
HAYDEN ROW
HOLLISTON
SUDBURY DIVIDE
COCHITUATE DIVIDE
Nobscot Hill
Gibbs Mountain
Pine Hill
Wolfpen Hill
Oak Hill
Wild Cat Hill
Magunco Hill
Brush Hill
Long Hill
Bear Hill
Fays Mountain
BOSTON & ALBANY RAILROAD
NEW YORK & NEW ENGLAND RAILROAD
Sudbury River
Cedar Swamp

supply must be filtered river water. The present collecting system extends through so large an area of porous ground that a large amount of water stored in the interstices of the ground is available for maintaining the supply when the river is low and there is consequently a smaller amount of water filtering from it into the ground.

It is impracticable to make any very close estimate of the amount of water which works of this kind will furnish without exhausting the water in the ground, until the water has been pumped at a high rate for several months during the dry portion of the year. It does not seem unreasonable, however, to expect that the present works will furnish continuously during the dry portion of a dry year from 3,000,000 to 3,500,000 gallons of water per day.

Consumption of Water. — The average daily consumption of water in Brookline for the past five years has been as follows: —

Consumption of Water, Brookline.

YEAR.	Population.	Annual Increase (Per Cent.).	Average Daily Consumption (Gallons).	Annual Increase.		Average Daily Consumption per Inhabitant (Gallons).	Average Daily Consumption, June to October, inclusive.	
				Gallons.	Per Cent.		Gallons.	Gallons per Inhabitant.
1890, .	12,103		877,000			72	1,003,000	83
		6.0		102,000	11.6			
1891, .	12,830		979,000			76	1,078,000	84
		6.0		67,000	6.8			
1892, .	13,600		1,046,000			77	1,170,000	86
		5.7		168,000	16.1			
1893, .	14,380		1,214,000			84	1,379,000	96
		5.4		111,000	9.1			
1894, .	15,153		1,325,000			87	1,558,000	103

NOTE. — All populations after 1890 are estimated.

Quality of Water. — The water supplied by the collecting system of the Brookline works is of excellent quality, and, as the distributing reservoir is covered so that the water is not exposed to the light in any place, it remains of excellent quality when delivered to the consumer.

There are two possible causes of future deterioration of the water from these works, the first being the one already referred to on page 10 of this report, — that any filtered river water may in time become of unsatisfactory quality. With regard to this point it may be said that water has been drawn from the ground near the Charles River at this place and at Newton and Waltham for about twenty years,

without showing signs of deterioration; but it should also be added that the works have not yet had the severe test which they will have in the future, when much larger quantities of water will be drawn from them.

The second is the danger from polluting matters turned into the ground within the drainage area which contributes directly to the ground-water supply. There is, on the West Roxbury side of the river, a rapidly increasing population within the territory from which a part of this supply comes; but the city of Boston is already considering the question of constructing a system of sewers to divert the sewage of this territory into its main sewerage system. The danger, therefore, of any serious deterioration of the water from either of these causes may be regarded as somewhat remote.

Future Supply. — The town of Brookline has acquired a very large area of land on both sides of the Charles River, but mostly on the Dedham side, for developing and protecting its water supply. On the West Roxbury side the land extends along the river from the pumping station lot to the Newton line, a distance of about 4,400 feet, and on the opposite side the land acquired consists of two tracts with a total frontage on the river at and below the pumping station of 8,100 feet. One of these tracts extends across a neck of land about 2,400 feet wide to another part of the river which, measured along the river, is several miles above the pumping station.

It does not seem improbable that these works can be developed so that they will furnish 5,000,000 gallons of water per day in the driest portion of a dry year; and, if the population of Brookline increases in accordance with the estimate given in Appendix No. 1, this quantity of water will provide 124 gallons per day per inhabitant during the months from June to October inclusive, until the year 1917.

At the present time the town of Brookline is authorized to take from the Charles River 3,000,000 gallons of water daily.

Medford.

[Population in 1890, 11,079; estimated population in 1895, 14,812.]

Description and Capacity of Sources of Supply. — The main source of supply of this city is Spot Pond, which is used jointly with Malden and Melrose, each municipality being entitled to one-third of its water. A description of Spot Pond and a statement of its capacity has already been given on page 35; and, as there indicated,

it will supply 520,000 gallons of water per day to each place in a dry series of years.

An auxiliary supply for Medford is now obtained by pumping water from three small streams or water courses just south of Spot Pond, on one of which Wright's Pond is situated. The total watershed added in this way is one-half of a square mile. At the present time there is a small receiving reservoir into which the water of the three streams flows, and a temporary pumping station beside it. When the streams furnish enough water to warrant pumping, it is pumped directly into the main pipe leading from Spot Pond to the city, and if more is pumped than the city uses, the surplus goes back into Spot Pond. The city is now developing this source by the construction of a new dam at Wright's Pond, increasing the storage capacity of the pond to 30,000,000 gallons, and it is estimated that when this development is completed the total capacity of the Medford sources will be 900,000 gallons per day in a dry series of years. This estimate is made upon the assumption that Medford will be able to utilize its third of the storage capacity in Spot Pond for the storage of the water supplied by the auxiliary watershed, and that the pond may be drawn down to a level 15 feet below high-water mark.

An auxiliary supply was obtained for a time from a system of tubular wells in the valley of a small brook just north of the thickly settled portion of the city, but this source is not now used.

Consumption of Water. — It is only since a meter was put on the main pipe, in September, 1892, to measure the quantity of water drawn from Spot Pond that the amount of water consumed could be determined. The following table, therefore, contains only the record of consumption for the past three years, and the record for 1892 covers only the last four months of the year: —

Consumption of Water, Medford.

YEAR.	Population.	Annual Increase (Per Cent.).	Average Daily Consumption (Gallons).	Annual Increase.		Average Daily Consumption per Inhabitant (Gallons).
				Gallons.	Per Cent.	
1892, . . .	12,600		568,000			45
		6.0		43,000	7.6	
1893, . . .	13,360		611,000			46
		5.7		88,000	14.4	
1894, . . .	14,122		699,000			49

NOTE. — All populations are estimated.

If the consumption of water in Medford were to increase in the future at the same rate that it has during the past two years, the capacity of the works after being fully developed would be reached in 1897. If Spot Pond should be full in the spring of 1897, the large amount of water stored in it would insure a sufficient water supply to Medford for two or three years longer even if the consumption of water during these years should be somewhat in excess of the safe capacity of the works.

Quality of Water. — A statement with regard to the quality of the Spot Pond water is given on page 37. By far the greater part of the water-shed of the auxiliary source south of Spot Pond is either owned by the city of Medford or is a part of the Middlesex Fells reservation controlled by the Metropolitan Park Commission. The population upon the water-shed at the present time is very small, and it is not likely to increase to any considerable extent. There is also some swampy land upon the water-shed, but this can readily be drained so that it will not seriously affect the quality of the water. On the whole, there seems to be no reason to doubt but that a water of good quality can be obtained from this auxiliary source.

Future Supply. — In addition to the present auxiliary source, there are said to be several small water-sheds within the city limits which it might be possible to develop so as to obtain a still further additional supply. I am not sufficiently informed with regard to these to know just how much water they will furnish, or whether the water can be obtained at a cost which would make it desirable to add them; but as a general rule the addition of small supplies which soon become outgrown is not in the line of true economy.

Revere and Winthrop.

[Population in 1890: Revere, 5,668; Winthrop, 2,726; total, 8,394. Estimated population in 1895: Revere, 7,707; Winthrop, 3,783; total, 11,490.]

Description and Capacity of Sources of Supply. — These towns are supplied by the Revere Water Company with ground water from two sources, one located in the town of Revere and the other in the vicinity of Cliftondale in the town of Saugus.

At Revere the water is obtained from two large wells and three groups of tubular wells located in the valley of a small brook. The area of the water-shed of this brook at a point opposite the wells is 430 acres. It is estimated that the wells will yield in a series of two

or more dry years an average of about 300,000 gallons of water per day; and, as the experience with these works has shown that there is a very large amount of storage in the ground, more water may be drawn during portions of the year provided the total amount indicated by the above estimate is not exceeded. Experience has also shown that an excessive draft upon these wells may cause an infiltration of sea water.

At Cliftondale the water is obtained from a system of tubular wells, which, with their present development, do not furnish sufficient water to supply the two towns without drawing upon the wells at Revere.

Consumption of Water. — The consumption of water in Revere and Winthrop for the past five years has been as follows: —

Consumption of Water, Revere and Winthrop.

YEAR.	Population.	Annual Increase (Per Cent.).	Average Daily Consumption (Gallons).	Annual Increase.		Average Daily Consumption per Inhabitant (Gallons).	Average Daily Consumption for Maximum Two Months in Summer.	
				Gallons.	Per Cent.		Gallons.	Gallons per Inhabitant.
1890, .	8,394		427,000			51	662,000	79
		5.3		46,000	10.7			
1891, .	8,835		473,000			54	666,000	75
		5.8		70,000	14.8			
1892, .	9,345		543,000			58	711,000	76
		6.3		180,000	33.2			
1893, .	9,936		723,000			73	921,000	93
		7.2		51,000	7.1			
1894, .	10,651		774,000			73	1,089,000	102

NOTE. — All populations after 1890 are estimated.

The table shows a very rapid increase in the consumption of water in these towns in recent years; and, if the capacity of the works has not already been reached, there is little doubt that it will be very soon, if the consumption continues to increase as it has. Revere and Winthrop have a large additional summer population, which accounts for the large increase in the consumption of water in summer. The large consumption of water per inhabitant in summer, as given in the table, is rather misleading, as in estimating it no account has been taken of the additional summer population.

Quality of Water. — The water furnished by the wells at Revere has always been a hard water, owing to the population upon the water-shed and possibly also to the proximity of the wells to the sea. Since August, 1893, there has been a very large increase in the

amount of chlorine in the water, indicating beyond all doubt that a small amount of sea water has been finding its way into the wells. If the wells were to remain unused, there is little doubt that the water would again become wholly fresh, but there is an uncertainty as to how long a time it would take. The wells at Saugus furnish water of good quality.

Future Supply. — There are no sources not now controlled by some other city or town for water-supply purposes, within a reasonable distance of Revere and Winthrop, from which these towns or the Revere Water Company could obtain, independently, any large additional amount of good water. It may be feasible to develop the present works at Cliftondale so that they will furnish a larger quantity of water than at present, but it does not seem probable that they can be made to furnish enough water to meet the rapidly increasing requirements of these two towns.

Melrose.

[Population in 1890, 8,519; estimated population in 1895, 11,656.]

Description and Capacity of Sources of Supply. — The main source of supply of this town is Spot Pond, which is used jointly with Malden and Medford, each municipality being entitled to one-third of its water. A description of Spot Pond and a statement of its capacity has already been given on page 35; and, as there stated, it will supply 520,000 gallons of water per day to each place in a series of dry years.

A temporary additional supply is purchased from a private water company, which obtains water from tubular wells in the valley of Spot Pond Brook on the westerly edge of the thickly settled portion of the town. It is not necessary to base an estimate of the capacity of these wells upon the amount which they will furnish during the dry months of a dry year, because in such a year recourse can be had to the large amount of water stored in Spot Pond to prevent a deficiency in the supply.

The capacity of these wells is not very definitely known, but it may be reckoned at an average of about 280,000 gallons per day, in addition to the supply from Spot Pond, making the total capacity of the present sources of supply about 800,000 gallons per day.

Consumption of Water. — The consumption of water in Melrose during the past five years has been as follows: —

Consumption of Water, Melrose.

YEAR.	Population.	Annual Increase (Per Cent.).	Average Daily Consumption (Gallons).	Annual Increase.		Average Daily Consumption per Inhabitant (Gallons).
				Gallons.	Per Cent.	
1890, . . .	8,519		581,000*			68
		8.6		135,000	23.2	
1891, . . .	9,250		716,000*			77
		8.3		4,000	0.6	
1892, . . .	10,021		720,000*			72
		8.8		68,000‡	16.0‡	
1893, . . .	10,900		652,000†			60
		5.0		29,000	4.4	
1894, . . .	11,441		681,000†			60

Note. — All populations after 1890 are estimated.
* Pump measurement.
† Meter measurement.
‡ Decrease.

The table indicates a marked decrease in the consumption of water from 1892 to 1893; but it may be questioned whether this is not due to the change in the method of measuring the water rather than to a decrease in the amount consumed, because a comparison of the two methods of measurement covering the same months showed that the pump measurement was considerably larger. The daily consumption of water per inhabitant in 1893 and 1894 was 60 gallons, and at this rate the present sources will supply a population of 13,333, which is the estimated population of Melrose in 1898.

Quality of Water. — A statement with regard to the quality of the Spot Pond water is given on page 37. The wells from which the auxiliary supply is obtained derive their water from a territory upon which there is a large population, and the water is, consequently, high in mineral matter and hard, and the hardness is increasing. The water is, however, at the present time of suitable quality for domestic use, particularly when it is mixed with the softer water of Spot Pond.

Future Supply. It may be feasible for Melrose to increase its water supply to a limited extent by means of driven wells at some place within the limits of the town; but there is no place within a reasonable distance from which it can obtain, by itself, at a reasonable cost, an abundant supply of good water.

Watertown and Belmont.

[Population in 1890: Watertown, 7,073; Belmont, 2,098; total, 9,171. Estimated population in 1895: Watertown, 7,551; Belmont, 2,628; total, 10,179.]

Description and Capacity of Sources of Supply. — These towns are supplied by the Watertown Water Supply Company with water taken from the ground near the Charles River in Watertown. The works for collecting water originally consisted of a filter gallery located near a portion of the river where the water is ponded by the dam of the Ætna Mills, and also near the line of a small brook which empties into the river below the dam. In order to provide a sufficient quantity of water to meet the increasing demands, the works have been extended from time to time; first by a series of tubular wells near the filter gallery, which, like the filter gallery, furnish good water, and subsequently by a large well and by tubular wells located farther down stream, which furnish water inferior in quality to that furnished by the filter gallery. The total capacity of these works is not definitely known, but during the drier portion of the year it is necessary to use the sources which furnish the poorer water in order to maintain the supply to the towns. The company has made very extended tests of the ground in the vicinity of its present works, and it does not seem probable that enough good water can be obtained in this vicinity to supply these two towns for any long time in the future.

Consumption of Water.—The consumption of water for the past five years has been as follows: —

Consumption of Water, Watertown and Belmont.

Year.	Population.	Annual Increase (Per Cent.).	Average Daily Consumption (Gallons).	Annual Increase.		Average Daily Consumption per Inhabitant (Gallons).	Average Daily Consumption for Maximum Two Months in Summer.	
				Gallons.	Per Cent.		Gallons.	Gallons per Inhabitant.
1890, .	9,171		360,000			39	464,000	51
		3.7		27,000*	7.5*			
1891, .	9,515		333,000			35	413,000	43
		4.4		74,000	22.2			
1892, .	9,935		407,000			41	522,000	53
		0.7		70,000	17.2			
1893, .	10,003		477,000			48	535,000	53
		0.1		63,000*	13.2*			
1894, .	10,008		414,000			41	512,000	51

Note. — All populations after 1890 are estimated.
* Decrease.

Quality of Water. — As already indicated, there is a difference in the character of the water obtained from different portions of the works of this company. The water of the original filter gallery and of the system of tubular wells near it is of excellent quality: while that from the wells farther down stream was found by special examinations in 1893 to contain iron and manganese, and not to show the high degree of chemical purification which water may attain when it filters for a sufficient distance through the ground under favorable circumstances. The water, however, was nearly free from bacteria, and was not then regarded as an unsafe water to supply to the towns. It would, however, be advisable to abandon the wells which furnish the inferior water when a better supply is available.

Future Supply. — It has already been indicated that there is no likelihood of obtaining any large additional supply of water from the ground in the vicinity of the present works, and I do not know of any source within a reasonable distance of these towns from which they or the water company can obtain a sufficient independent supply of good water at a reasonable cost.

The water commissioners of the town of Belmont recently caused investigations to be made of sources from which an independent supply of water might be obtained for that town. The engineer employed by them reported that a supply could be obtained from Clematis Brook at an estimated cost of $146,707, exclusive of land or water rights and of the cost of the distributing system which is now owned by the town. This sum equals $55.82 for each inhabitant in 1895, using the estimated population as given on page 4.

Arlington.

[Population in 1890, 5,629; estimated population in 1895, 6,573.]

Description and Capacity of Sources of Supply. — This town is supplied with water by gravity from a storage reservoir which has an area of 31 acres, a capacity of 77,000,000 gallons and a water-shed, including the area of the reservoir, of 2.25 square miles. There is an additional water-shed of .49 of a square mile from which water flows into the Great Meadows, so-called, in Lexington; and from these meadows, which can be flooded so as to form a very shallow reservoir, the water can be turned into the main reservoir when an additional supply is needed, or it can be wasted through another outlet. Along one side of the storage reservoir there is a filter gallery with branches running out beneath the reservoir, and

enough filtered water is obtained in this way to supply the town during more than half of the year. There is also a connection between the brook which feeds the reservoir and the filter gallery, by means of which the brook water can be turned into the filter gallery and thence into the pipe leading to the town without passing through the reservoir.

It is estimated that the storage reservoir will supply about 530,000 gallons per day in a dry year without any water being turned into it from the Great Meadows. This reservoir is at so low a level that it will not supply the whole of the town by gravity, and works are now nearly completed for taking water from the ground at one side of the Great Meadows and near the East Lexington railroad station, and pumping it to supply the higher portions of the town. The total capacity of all the sources controlled by the town is somewhat indefinite, but it may be reckoned at about 750,000 gallons per day in the driest year.

Consumption of Water. — The amount of water consumed by the town is not measured in any way. The large number of people to whom the present water supply is not available would tend to make the consumption lower than in most towns, but on the other hand a very large amount of water is used by the market gardeners in the town in summer.

Quality of Water. — The water of the storage reservoir quite frequently contains abundant growths of the minute organisms which give water a disagreeable taste and odor, so that it is a very unsatisfactory water for drinking. The water of the filter gallery is of more satisfactory quality than that of the reservoir, notwithstanding the fact that the purification by filtration is far from being complete. The water of the brook feeding the reservoir comes from a territory where there is much manured land and some population, and, while it may be more attractive to the consumers than the water drawn from the storage reservoir, it is not as safe for drinking when taken directly into the pipes as it would be after storage in the reservoir. The water of the driven wells, from which the high-service supply is to be taken, will probably be of better quality than any other water supplied to the town except the filtered water of the filter gallery; but even the well water was found by analyses of samples taken from test wells to contain an undesirable amount of iron, which may increase with continuous pumping, so that it is not expected to prove a water of wholly satisfactory quality.

Future Supply. — Aside from the present sources of supply, there seems to be no available source within a reasonable distance of the town from which a satisfactory independent supply can be obtained at a reasonable cost.

Winchester.

[Population in 1890, 4,861; estimated population in 1895, 6,930.]

Description and Capacity of Sources of Supply. — This town is supplied with water from three storage reservoirs situated in the Middlesex Fells, and known as the North, Middle and South reservoirs.

The North Reservoir, built in 1873, was the original source of supply of the town. It has an area of 59 acres, a storage capacity of 159,000,000 gallons in the upper ten feet, a total storage capacity according to an old report of 259,000,000 gallons and a water-shed of 442 acres, exclusive of the area of the reservoir. Making allowance for a leakage of 50,000 gallons per day past the dam, the source will yield by itself about 578,000 gallons of water per day in a series of dry years; but used in connection with the other sources, where the reservoirs are larger in proportion to the water-sheds, its capacity may be reckoned at about 640,000 gallons per day.

The Middle Reservoir naturally forms a part of the South Reservoir, but is separated from it by a dam. It was formed by flooding an extensive swamp to a depth of about 13 feet. It has an area of 58 acres and a water-shed of 134 acres, exclusive of the area of the reservoir. Its capacity is sufficiently large to make available practically all of the water which the water-shed will supply, amounting to about 209,000 gallons per day in a series of dry years. The water from this reservoir overflows into the South Reservoir.

The South Reservoir, which was completed in 1891, has very bold shores to a depth of 20 feet or more below high-water mark, and a maximum depth of about 40 feet just above the dam. Its area is 82 acres, and the area of the water-shed contributing directly to it, exclusive of the reservoir, is 197 acres. Its storage capacity is so very large in proportion to the area of the water-shed that, like the Middle Reservoir, it will render available practically the whole flow from the water-shed, amounting to about 308,000 gallons per day in a series of dry years; but as there is a leakage of about 116,000 gallons per day past the dam, the available yield, exclusive of the overflow from the Middle Reservoir is about 192,000 gallons per day.

It is stated that there are certain outlying areas amounting to 43 acres, from which the surface water can easily be diverted into the South Reservoir, and when diverted the yield of this reservoir will be increased about 45,000 gallons per day, making the total yield 237,000 gallons per day.

The foregoing statements, representing the quantity of water which each of the reservoirs will furnish, are subject to considerable modification when we take into account the present or future quality of the water which these reservoirs will furnish.

In the first place, there are 184 of the 442 acres of water-shed tributary to the North Reservoir upon which the populated part of the town of Stoneham has begun to encroach. Four hundred people now live upon these 184 acres, equivalent to 1391 per square mile. It is feasible to divert from the North Reservoir the water coming from this territory, and it should be done; but when done, the daily yield of the North Reservoir, used in connection with the other reservoirs, will be reduced from 640,000 to 353,000 gallons per day.

Owing to the large area of swampy land flowed by the Middle Reservoir, the water contains so much organic matter that it is not of suitable quality to supply directly to the town or to turn into the other reservoirs without being filtered. It may be possible to divert into the other reservoirs a portion of the water which under present conditions would flow into this reservoir, and possibly to filter into them a part or the whole of the remainder of the water which this reservoir will supply.

The South Reservoir when first filled contained water of very poor quality, but it has improved so much since that time that it has been used during the past six months in one section of the town, and it may be reckoned as one of the available sources of the town.

The total capacity of the present sources of supply evidently depends much upon where the line is drawn between good and bad water, and also upon whether it is feasible to purify the water of the Middle Reservoir, which is now unsuitable for use, and to recover water which is lost by leakage through the dams. The quantities obtained by different assumptions are given in the following tabulation, beginning with the water of the best quality: —

	Gallons per Day.
North Reservoir, excluding the 184 acres of populated territory in Stoneham,	353,000
South Reservoir, exclusive of overflow from Middle Reservoir,	190,000
Additional from South Reservoir if water is diverted into it from a small outlying water-shed,	45,000
	588,000
Middle Reservoir, assuming that a part of the water coming from its water-shed may be diverted into the other reservoirs and that the remainder may be filtered into the other reservoirs,	209,000
	797,000
Leakage from dams if recovered and utilized: —	
South Dam,	116,000
North Dam,	50,000
	963,000

Consumption of Water. — No record is kept of the amount of water consumed by the town. From 1891 to 1894, when the whole supply of the town was taken from the North Reservoir, there were three periods varying from nine to eleven months in length during which the reservoir did not overflow; and by estimating the amount of water which the reservoir probably received from its water-shed and from the rain which fell directly into it during this period, and making proper deductions for the amount of water lost from the reservoir by evaporation and by leakage from the dam, it is feasible to ascertain approximately the amounts drawn for the use of the town. They amounted to an average of about 70 gallons daily per inhabitant.

It is stated that, owing to the fact that the town has a supply of water in excess of its present needs, large quantities of water are supplied for irrigation purposes and for manufacturing, but that these extravagant uses of water would be promptly checked if there was danger that the supply would prove insufficient.

While a reduction might be made in the amount of water consumed by preventing the use of water in the manner described, it does not seem probable, when the conditions in Winchester are compared with those in other towns, that the consumption would be reduced to less that 60 gallons per head per day.

If the daily consumption of water per inhabitant in 1895 is reckoned at 60 gallons, and allowance is made for an increase of four gallons every five years, we have, by using the estimated future pop-

ulation of the town as given in Appendix No. 1, the following estimated consumption up to the year 1915: —

YEAR.	Estimated Population.	Consumption per Day per Inhabitant.	Total Consumption per Day.
1895,	6,930	60	415,800
1900,	8,350	64	534,400
1905,	10,125	68	688,500
1910,	12,225	72	880,200
1915,	14,725	76	1,119,100

By comparing this table of estimated consumption of water with the capacity of the sources as given above, and by making allowance for the fact that with the large amount of water which Winchester has stored in its reservoirs it can draw upon its surplus storage to maintain its supply for about two years after the permanent capacity of its sources has been reached, it is found that the North and South reservoirs, inclusive of the small outlying water-shed and exclusive of the Middle Reservoir, will furnish a supply until 1904. If the water of the Middle Reservoir is utilized the supply will last until 1910, and if the leakage from the dams is also recovered and utilized the time will be extended until 1914.

Quality of Water. — The water of the North Reservoir is generally of good quality, but it has been affected at times by the presence of large numbers of the minute organisms which give the water an unpleasant taste and odor. The water would be rendered much safer for drinking and would be less likely to contain these organisms if the drainage from the 184 acres already referred to in Stoneham were diverted from the reservoir.

The South Reservoir, as already stated, contained a water of very poor quality when it was first filled; but there has been a steady improvement in the quality, and it seems probable that the water will be as good as that of the North Reservoir if the overflow of water from the Middle Reservoir into the South Reservoir is prevented.

The quality of the water in the Middle Reservoir has already been fully stated.

Future Supply. — There does not appear to be any source from which the town of Winchester can obtain an additional water supply

when the capacity of its present sources is reached which will furnish water of good quality as cheaply as the proposed metropolitan system.

Swampscott and Nahant.

[Population in 1890: Swampscott, 3,198; Nahant, 880; total, 4,078. Estimated population in 1895: Swampscott, 3,592; Nahant, 1,125; total, 4,717.]

Description and Capacity of Sources of Supply. — These towns are supplied by the Marblehead Water Company with ground water from wells in Swampscott. The pumping station and the original well, and many driven wells which have since been added to increase the capacity of the works, are near Stacy's Brook only a short distance from the sea, and there are other wells driven more recently in the valley of a tributary of this brook, from a quarter to a half mile from the original well, which are known as the Paradise Road wells. The wells located in the valley of Stacy's Brook have become affected by the infiltration of a small amount of sea water in the same manner as the wells of the Revere Water Company at Revere.

The Paradise Road wells do not furnish enough water to meet the increased demands due to the large summer population from about the first of June to the first of October, and it is therefore necessary during this period to use some of the water from the sources near the pumping station which have become affected by the infiltration of sea water.

Consumption of Water. — The average daily consumption of water in Swampscott and Nahant during the past five years has been as follows:—

Consumption of Water, Swampscott and Nahant.

YEAR.	Population.	Annual Increase (Per Cent.).	Average Daily Consumption (Gallons).	Annual Increase.		Average Daily Consumption per Inhabitant (Gallons).	Average Daily Consumption for Maximum Two Months in Summer.	
				Gallons.	Per Cent.		Gallons.	Gallons per Inhabitant.
1890, .	4,078		229,000			56	519,000	127
		3.3		28,000	12.2			
1891, .	4,212		257,000			61	535,000	127
		3.5		6,000	2.3			
1892, .	4,360		263,000			60	568,000	130
		2.6		28,000	10.7			
1893, .	4,475		291,000			65	647,000	145
		2.2		33,000	11.3			
1894, .	4,575		324,000			71	592,000	129

NOTE. — All populations after 1890 are estimated.

Plan No. 4


STATE BOARD OF HEALTH
METROPOLITAN WATER SUPPLY
WATER-SHED
OF THE
NASHUA RIVER ABOVE CLINTON
DECEMBER, 1894.
SCALE
This map is taken from the original sheets of the State Topographical Survey, except in the vicinity of the Nashua and Quinepoxet Rivers, where exact surveys, made by the State Board of Health, have been used.
PROPOSED NASHUA RIVER RESERVOIR
AREA RECOMMENDED FOR WORCESTER WATER SUPPLY
NASHUA RIVER WATER-SHED
PROPOSED AQUEDUCT FROM THE NASHUA RIVER TO THE SUDBURY WATERSHED
FUTURE TUNNEL
LEOMINSTER
Long Hill
Rayberry Hill
Ball Hill
Wachusett Mountain
Pine Hill
Rocky Hill
Justice Hill
Bee Hill
EAST PRINCETON
WEST STERLING
PRINCETON CENTER
Brown Hill
EAST HUBBARDSTON
Calamint Hill
George Hill
SOUTH LANCASTER
LANCASTER
LANCASTER COMMONS
BOLTON
STERLING CENTER
Fitch Hill
CLINTON
Barrett Hill
STERLING JUNCTION
STERLING CAMP GROUNDS
FRYVILLE
Holbrook Hill
Rice Hill
OAKDALE
RUTLAND CENTER
QUINEPOXET VILLAGE
HARRISVILLE
WEST BOYLSTON
BOYLSTON
French Hill
WEST BERLIN
BERLIN
Wheeler Hill
JEFFERSONVILLE
Maiden Hill
EAGLEVILLE
UNIONVILLE
Davis Hill
HOLDEN CENTER
BOYLSTON CENTER
Mt Pisgah
SOUTH BERLIN
CHAFFINVILLE
Turkey Hill
Fox Hill
SUMMIT STA.
STRAW HOLLOW
Bartlett Hill
NORTHBOROUGH
PAXTON CENTER
WORCESTER WATER SUPPLY
Stone House Hill
Winter Hill
Indian Hill
Asnebumskit Hill
FITCHBURG RAILROAD
WORCESTER BRANCH
BOSTON & MAINE RAILROAD
CENT. MASS. DIV.
OLD COLONY SYSTEM
N.Y., N.H. & H. R.R.
FITCHBURG & WORCESTER BR.
West Wachusett Brook
East Wachusett Brook
Nashua River
Stillwater River
P R I N C E T O N
W O R C E S T E R

Quality of Water. — The water of the wells in Paradise Road is of good quality, although somewhat harder than is desirable. The water of the wells in the valley of Stacy's Brook, aside from the infiltration of sea water, is derived from a territory containing a large population, so that it is hard and contains much mineral matter. The analyses, however, show that the amount of organic matter is very small, indicating, as far as a chemical analysis can, a very efficient purification of the water by filtration.

Future Supply. — The water company is now engaged in an investigation with a view to obtaining an additional water supply from the ground in the northerly portion of the town; but, should this prove as large as can reasonably be expected, it is not likely to meet the increasing needs of the towns for more than a short time. It is also possible that a further additional supply may be obtained from the valley of Forest River in Salem; but, even if this should be the case, it may be questioned whether it properly belongs to Swampscott and Nahant or to Marblehead, which now has only a limited supply of water and already has works located in the valley of this river. Aside from these sources, there seems to be no place within a reasonable distance from which either Swampscott and Nahant or Marblehead can obtain independently any large additional supply of water at a reasonable cost.

Lexington.

[Population in 1890, 3,197; estimated population in 1895, 3,645.]

Description and Capacity of Sources of Supply. — This town is supplied with water by the Lexington Water Company. Water was introduced in 1884 from wells on the border of a meadow near Vine Brook in Lexington. Additional wells have been added from time to time, so that there are now four large wells and one deep tubular well in the vicinity of the pumping station, and another well and a covered gallery nearer the village of Lexington.

In addition to these sources a storage reservoir was built upon the upper portion of Vine Brook in 1894, which is now being filled with water for the first time. It has a capacity of about 14,250,000 gallons, and, if raised an additional foot by flash-boards, of about 16,000,000 gallons. Its area is about $5\frac{1}{2}$ acres, and its water-shed, including the area of the reservoir, is about .30 of a square mile. An additional ground-water supply was also developed during the

construction of the dam and the laying of the pipe from the reservoir to the pumping station, which has been turned into this pipe.

The wells are said to furnish an ample supply to meet present requirements for all except four or five months in the drier portions of the year, so that until the consumption increases it will only be necessary to draw water from the reservoir during this period.

It is impracticable, with the information now at hand, to estimate definitely the amount of water which these combined sources will furnish; but it does not seem probable that they will furnish during the dry months of a very dry year more than from 200,000 to 300,000 gallons per day.

Consumption of Water. — No records are kept of the daily consumption of water, but it has been necessary in summer to place restrictions upon the amount of water used for some purposes. If we take the estimated population in 1895 as already given, and reckon upon a summer use of 50 gallons per inhabitant, the total daily consumption of water will be 182,250 gallons.

While the foregoing figures cannot be regarded as other than approximations, it seems probable that, with the increasing population and the tendency in nearly all places for the consumption of water per inhabitant to increase, this town will need an additional supply about as soon as a metropolitan supply will be available.

Quality of Water. — The water taken from the ground by the Lexington Water Company is of good quality. The quality of the water which the storage reservoir will furnish is not yet known, but it is expected that it will be suitable for use.

Future Supply. — Extended investigations were made by the water company in 1893 for the purpose of obtaining an additional water supply for the town; but, aside from the developement of the Vine Brook water-shed by the construction of the storage reservoir recently completed, no satisfactory source was found. The larger streams within a reasonable distance of the town contained water of unsatisfactory quality, owing to the large amount of low, swampy land draining into them; and by following these streams toward their head waters it was found that when a point was reached where the water was good, the quantity of water available was too small to warrant the construction of works or to supply the growing requirements of the town. Investigations with a view to obtaining a ground-water supply near the larger streams indicated that it would not be feasible to obtain a supply in this way.

Outline of the Proposed Plan for taking an Additional Water Supply from the Nashua River.

An outline of the plan recommended for taking an additional water supply from the Nashua River, and a statement with regard to the quality, quantity and cost of the water to be obtained from this source, will be given in this place so that it will be feasible to consider intelligently in a subsequent chapter the question of whether it is better for the different cities and towns to obtain their water supplies as a part of the metropolitan district or by independent action. A statement with regard to the sources investigated and not recommended, and a more detailed description of the works for taking water from the Nashua River and for distributing it through the metropolitan district, will be given in the latter portion of my report.

A careful preliminary examination of the sources from which any large additional water supply might be obtained for the metropolitan district indicated that the South Branch of the Nashua River just above Clinton, used in connection with the Sudbury River and Lake Cochituate, offered the greatest promise of furnishing an ample supply of good water at a reasonable cost; and the surveys and investigations with reference to obtaining an additional supply from this source were made with special care, in order to determine with certainty the feasibility of the plan, its cost, and the opportunities for supplementing the supply in the future from other sources if the additional supply from the Nashua River should prove insufficient.

The situation of the Nashua River water-shed with relation to the Sudbury and Cochituate water-sheds and to the metropolitan district, together with the location of present and proposed aqueducts leading to this district and for conveying the water from the Nashua River to the Sudbury water-shed, is shown on Plan No. 2.

The principal features of the proposed plan are as follows: —

A very large storage reservoir upon the Nashua River.

An aqueduct capable of conveying 300,000,000 gallons of water per day from this reservoir to the Sudbury water-shed.

The use of the present Sudbury and Cochituate aqueducts of the city of Boston for conveying water to Chestnut Hill Reservoir until their full capacity has been utilized.

An additional aqueduct, capable of conveying 250,000,000 gallons of water per day, to be built in the not distant future, for conveying water

from Reservoir No. 5 of the Boston Water Works to the metropolitan district.

A low-lift pumping station at Chestnut Hill Reservoir and a system of main pipes for supplying all of the lower portions of the metropolitan district until the aqueduct last mentioned is built, and afterward to supply to these portions of the district the water brought by the Sudbury and Cochituate aqueducts.

The use of Spot Pond in Stoneham as a low-service distributing reservoir.

The use of the present pumping station at Chestnut Hill Reservoir and the construction of a new pumping station in Malden, with corresponding main pipe systems, for supplying respectively the southern and northern high-service districts.

Two small pumping stations and pipe systems for supplying water to comparatively small populations at a still higher level.

Description and Capacity of Source. — The streams which unite in West Boylston to form the South Branch of the Nashua River take their rise on the easterly and southerly slopes of Mt. Wachusett, in the central part of the State (Plan No. 4). The drainage area of the river above the proposed point of taking, in the town of Clinton, is 118.23 square miles, and upon this area there are no large towns or villages. The largest town is West Boylston, which in 1890 had a population of 3,019, and has grown very little since 1870, when it had a population of 2,862. The construction of the proposed reservoir would materially decrease the population of this town by flowing the sites of mills and houses in the villages of West Boylston and Oakdale. In comparison with the Sudbury and Cochituate water-sheds (Plan No. 5) and nearly all others in the vicinity of Boston, this water-shed contains a small area of swampy land. There are factories upon some of the streams above the proposed reservoir, but it is feasible to divert the objectionable portion of the manufacturing wastes and to purify them by filtration, and in the same way to prevent the contamination of the water by the wastes from the population in the villages.

The proposed reservoir is so very large that all of the water flowing in this river in an ordinary year, amounting to an average of about 120,000,000 gallons per day, may be utilized. The reservoir will also equalize the flow of water in a series of years as dry as any which have occurred in the last forty or fifty, so as to supply an average of 105,000,000 gallons per day. In addition to this amount, if it should be found in these dry years that the reservoir had been drawn down so much that it would not be likely to fill in

the spring if water should be drawn freely from it for the supply of the metropolitan district, the flow from this source could be restricted or stopped, and in its place the portion of the spring flow from the Sudbury water-shed, which now runs to waste over the lowest dam, might be used to furnish the supply to the district. This water which flows in the Sudbury River in the spring of the year does not have the benefit of any long storage; but it is now used for the water supply of the city of Boston, and by the drainage of swamps and the further diversion and purification of sewage from the villages upon the water-shed can be made better in the future than it is now. By utilizing this water which is now wasted from the Sudbury River, the capacity of the combined sources in a very dry series of years will be increased by an average for the whole year of 6,000,000 gallons per day, making the total addition attributable to the Nashua River and the proposed reservoir upon it of 111,000,000 gallons. This quantity, added to the 62,000,000 gallons per day which the Sudbury and Cochituate water-sheds will supply after Reservoir No. 5 is completed, will make the total capacity of the combined sources 173,000,000 gallons.

In making the above estimates I have reckoned upon drawing from the Nashua Reservoir but five-sixths of its storage capacity, so that there would remain for emergencies 10,500,000,000 gallons, equal to a supply of 105,000,000 gallons per day for one hundred days; and I have not taken into account the fact that the Nashua water-shed, on account of its steeper slopes and smaller area of swamps, gives less opportunity for evaporation, and will consequently yield a larger quantity of water per square mile than the Sudbury water-shed, upon the flow from which these estimates have been based. In all ordinary years a draft of 100,000,000 gallons daily from the Nashua River would not draw from the reservoir more than one-sixth of its storage capacity, or lower it more than nine feet below high-water mark.

Investigations have shown that, if the population of the metropolitan district becomes so large that the Nashua River in connection with existing sources will not furnish a sufficient quantity of water, an additional supply of water of good quality and of almost unlimited quantity can be obtained from tributaries of the Assabet River and the Ware, Swift and Deerfield rivers. The cost of adding the tributaries of the Assabet River and the Ware River will be comparatively small; and if the population of the metropolitan district should ever

become so large as to require the addition from time to time of the other streams, the cost would not be large in proportion to the greatly increased population to be supplied at the time.

Storage Reservoir. — The proposed storage reservoir on the Nashua River has a capacity of 63,068,000,000 gallons, a depth of water near the dam above the level of the existing millpond of 107 feet, and an average depth of 46 feet. Its area when full is 6.56 square miles, which will make it the largest body of fresh water in Massachusetts, and its high-water mark is 385 feet above the level of high tide. In order to build the reservoir, it is necessary to construct a dam across the river and dikes to the north and south of the main dam, to prevent the water from overflowing from the reservoir in other directions. It is also necessary to relocate many roads and the Central Massachusetts Railroad which now runs lengthwise through the proposed reservoir for nearly its whole length. The site of the reservoir is practically free from swamps; but to insure an improvement in the quality of the water by storage it is proposed to remove all of the soil and vegetable matter before filling it with water. The entire cost of constructing the reservoir is estimated to be $9,105,000, — a very large sum of money, and yet not large in proportion to the quantity of water stored, as will be seen by the following comparative table: —

Cost per Million Gallons of Water stored.

CITY.	NAME OF RESERVOIR.	Acres Flowed.	Storage, in Million Gallons.	Cost per Million Gallons
Boston, . .	Reservoir, No. 1, . .	143	280	$918
" . .	" No. 2, . .	134	530	879
" . .	" No. 3, . .	253	1,080	388
" . .	" No. 4, . .	167	1,400	581
" . .	" No. 6, . .	185	1,530	566
" . .	" No. 5, . .	1,220	7,438	336*
Cambridge .	Proposed reservoir on Hobbs Brook,† . .	350	1,500	400
	Proposed reservoir on Nashua River, . .	4,195	63,068	144

* Based upon estimated cost of reservoir.

† The figures for this reservoir are based upon preliminary estimates of cost and capacity, as given in the annual report of the Cambridge Water Board for 1893.

The proposed reservoir has been designed of larger capacity than would be economical if the quantity of water to be obtained from it were the only consideration, and the removal of the soil from the site of the reservoir is obviously work which relates almost wholly to improving the quality of the water. Of the total cost of the reservoir, it may fairly be said that fully $4,000,000 has reference to the quality of the water rather than its quantity. The removal of the soil will prevent the water from taking up organic matter from it, and owing to the very large size of the reservoir, the water will be stored long enough to permit it to improve very much in character by bleaching and by the decomposition and disappearance of the organic matter which the water entering the reservoir contains.

Works for conveying Water from the Nashua River to the Metropolitan District. — From the dam of the storage reservoir on the Nashua River it is proposed to construct an aqueduct 8.87 miles long, capable of conveying 300,000,000 gallons of water per day. This aqueduct will extend to a point in the Sudbury River watershed 3.03 miles above the upper end of Reservoir No. 5. From the end of the aqueduct an open channel formed by enlarging the channel of an existing brook will convey the water to the reservoir. The total cost of the aqueduct and open channel is estimated to be $2,265,000. When the water has reached Reservoir No. 5 it will flow through the existing reservoirs and aqueducts of the city of Boston to Chestnut Hill Reservoir.

The present sources of the city of Boston, as already stated, will yield when developed 62,000,000 gallons of water per day, and the aqueducts belonging to the city have enough surplus capacity to supply the district until the average consumption becomes 100,000,000 gallons per day in excess of what local sources will furnish.

It will be necessary, however, in order to utilize the full capacity of the Sudbury aqueduct, to lay an additional 48-inch siphon pipe 1,800 feet long across the Rosemary valley; and, in order to convey the water from the Nashua River and Reservoir No. 5 to the metropolitan district without permitting it to mingle with the water which comes down the Sudbury River, it will also be necessary to lay a second 48-inch pipe 5,185 feet long from Dam No. 3 to the gate house at Dam No. 1.

When the amount of water to be conveyed exceeds the 100,000,000 gallons per day already mentioned, it will be necessary to have a new aqueduct ready for use for conveying the water to the metropolitan

district. It was found upon investigation that by starting this aqueduct from Reservoir No. 5 it would be feasible to reach the edge of the metropolitan district about 60 feet higher than the existing aqueducts, and to provide for the lower portions of the district a gravity supply under a greater pressure than is furnished by Chestnut Hill Reservoir. It is also feasible, on account of the greater elevation of Reservoir No. 5, to give the new aqueduct for nearly half of its length twice as much slope as the Sudbury and about eight times as much slope as the Cochituate aqueduct; and this portion can, consequently, be made smaller in proportion to the amount of water to be conveyed. The remaining portions will have about the same slope as the Sudbury aqueduct.

The proposed aqueduct has a length of 13.48 miles, and is designed to carry when running full 250,000,000 gallons of water per day. It is to be constructed of masonry except for a distance of 400 feet at Dam No. 5 and 4,100 feet at the crossing of the Sudbury River, where pipes will be used. The terminus of the aqueduct is upon high land in the easterly portion of the town of Weston, not far from the Charles River, and from it the water will be distributed to the metropolitan district through pipes, except at one place where a section of aqueduct may be used. The pipes for supplying the portion of the district south of Charles River will run to Chestnut Hill Reservoir, where they will be connected with pipes previously laid; and those for supplying the portion north of Charles River will run through Waltham and Belmont to Arlington and Medford, where they will connect with main pipes previously laid, communicating with the cities and towns in the district and with Spot Pond, into which any surplus water brought by this aqueduct will flow.

On the line of the pipe leading from the aqueduct in Weston to Chestnut Hill Reservoir, the land for 1.94 miles west from the reservoir is high enough so that an aqueduct may be substituted for the pipes.

As additional pipes leading from the aqueduct at Weston can be laid from time to time, it may not be necessary to lay at first more than one line of pipes in each of the directions above indicated.

The estimated cost of the aqueduct from Reservoir No. 5 to Weston at the present prices is $3,226,000; of one line of 48-inch pipe and the section of aqueduct above mentioned leading to Chestnut Hill Reservoir, $1,160,000; and of the other line of 48-inch pipe,

completing a continuous line to Medford Centre, $596,000. It is estimated that the aqueducts and pipes just mentioned, costing in all $4,982,000, should be ready for use in 1905.

There is a favorable opportunity for building an equalizing reservoir at the terminus of the aqueduct in Weston; but this will not be necessary until a large quantity of water is run through the aqueduct.

Distribution of Water through the Metropolitan District. — The following description relates to the distribution of water to all of the cities and towns within ten miles of the State House. In order to avoid complicating my report, I will not attempt to describe what may be done if some of the cities and towns are either temporarily or permanently omitted, because it is obvious in most cases that the only changes will be the omission of the branches leading to these cities or towns; but in some cases there will also be a reduction in the sizes of some of the remaining pipes.

As already stated, the Nashua River water will for several years be conveyed through existing aqueducts to Chestnut Hill Reservoir, and will have to be distributed to the metropolitan district from this place. By far the larger part of the population of the district is located upon land at a comparatively small elevation above the sea level, and might be supplied by gravity with water from Chestnut Hill Reservoir. Much of this population, however, is already supplied with water from sources which are about 20 feet higher than Chestnut Hill Reservoir, and at or very nearly at the level of Spot Pond in Stoneham; and it would not be advisable to diminish the existing pressures.

Upon examining further into the question of the best pressure to adopt, it was found that the gravity supply from Chestnut Hill Reservoir was inadequate to the needs of the low-service district of the city of Boston, now that so many high buildings are being built; and, taking this into account, and the many advantages of having the whole low-service district upon the same pressure, it was decided to provide a pumping station near Chestnut Hill Reservoir to lift to a small height all of the water required for the low-service district. By lifting the water from 30 to 40 feet and extending large pipes northerly through the district, it is feasible to utilize Spot Pond as a distributing and equalizing reservoir, and to furnish water to the whole low-service district with a pressure as great or greater than at present. The increase in pressure in Boston would be that due to an additional head of from 30 to 40 feet, and in Cambridge the head in

the present high-service district would be increased about 30 feet and in the low-service district about 75 feet.

Plan No. 6 shows the method of distributing water throughout the metropolitan district. It is proposed to lay two 48-inch pipes from the pumping station at Chestnut Hill Reservoir to the centre of Medford, where these pipes will diverge, one continuing directly to the southern end of Spot Pond and the other to Malden. Another 48-inch pipe would run from the easterly side of Spot Pond to Malden, connecting with the pipe above mentioned, and providing at this place a very great supply of water. From this junction a 48-inch pipe would extend to Broadway in Everett, and a 42-inch pipe would be continued to Broadway in Chelsea, where a connection would be made with the existing pipes leading to East Boston. The existing pipes leading from Everett to Somerville, and from Chelsea through Charlestown to Boston, would furnish important connections for maintaining a supply of water to any of these places if it should be necessary to shut off the main lines, and for concentrating a very large supply at any of them if a great fire should occur. Other cities and towns in the low-service district would be provided for in an equally liberal manner from the main pipes already mentioned or from branches extending from them as indicated upon the plan.

In order to supply the higher lands in the northerly portions of the metropolitan district, and the city of Lynn and the towns of Revere and Winthrop, it is proposed to establish a pumping station near the junction of the 48-inch pipes in Malden; and from this as a centre to pump the water through a radiating system of pipes to the higher portions of Somerville, Medford, Malden, Everett, Chelsea and Winchester, and for the supply of the whole of Woburn, Stoneham, Wakefield, Melrose, Revere, Winthrop, Breed's Island, Saugus, Lynn, Nahant and Swampscott.

The main distributing reservoir of this system will be located in the Middlesex Fells at an elevation of 270 feet above high tide. This reservoir would be higher than the reservoirs in most of the cities and towns to be supplied from it, and these places could therefore be supplied under a higher pressure than at present, if it should be found desirable, or the water could be permitted to flow into the present reservoirs and tanks by using a regulating gate which would prevent them from running over. In any case, it is proposed to keep existing reservoirs filled so that they may be

utilized in case of fire or other emergency. In the remaining places water would be supplied under about the same pressure as at the present time.

The town of Lexington and a portion of Arlington are at too high a level to be reached by the high-service system just described, and it is therefore proposed to erect a small pumping station in Arlington, to pump from the low service for the supply of these elevated districts.

On the southerly side of the district it is proposed to provide "high" and "extra high" service supplies, corresponding to those on the northerly side, all of the pumping to be done at Chestnut Hill Reservoir. The high-service pumping station will be the present high-service pumping station in the city of Boston, and it will be used in connection with the high-service reservoirs of the city of Boston and the present open, and little used, reservoirs of the town of Brookline and the city of Newton. There would also be a large tank constructed in connection with this service in the city of Quincy, near Mt. Wollaston. This system would supply water for the high-service district of Boston, and for Watertown, Belmont, Waltham and Quincy, and the greater part of Newton, Brookline, Hyde Park and Milton.

The southern extra high service would supply water to elevated districts containing a comparatively small population, in Boston, Newton, Brookline, Hyde Park and Milton, and the pumps, which would be of small size, would be located in the low-service pumping station at Chestnut Hill Reservoir.

The works for distributing water throughout the whole metropolitan district, as shown upon Plan No. 6 and indicated by the foregoing description, include two important pumping stations, at Chestnut Hill and Malden, and a small one at Arlington, one new distributing reservoir, one iron tank, and 95.22 miles of pipe; and the entire estimated cost, including the improvement of Spot Pond is $5,584,-000.

Quality of Water. — The description already given of the Nashua River source and the opportunities for developing it indicate that it will furnish a water of unusually good quality. It will be instructive, however, to make a comparison with the larger sources now used for water-supply purposes and with others which have been considered with reference to the water supply of the metropolitan district.

SOURCES.	Population per Square Mile (1894).
Deerfield River, above Shelburne Falls,	21
Swift River, at Belchertown,	30
Ware River, at Cold Brook,	32
Lake Winnipiseogee,	35
Assawompsett Pond,	36
Tributaries of Assabet River,	60
Nashua River, above Clinton,	**69**
Ipswich River, at Danvers,	72
Stony Brook, at Cambridge dam,	107
Shawsheen River, at old Middlesex Canal Crossing,	123
Charles River, above South Natick,	179
Sudbury River,	376-165
Lake Cochituate,	770-185
Saugus River, at Howlett's dam,	709
Upper Mystic Lake,	984

NOTE. — Where two figures are given for population per square mile, the first is the total population and the second is the population remaining after deducting the districts from which the sewage has already been or is soon to be diverted to a point outside of the water-shed.

It will be seen, by reference to this table, that the Nashua River stands seventh in order in population per square mile. Four of the sources which have a smaller population are those which may be used in the future to supplement the supply from the Nashua River. The population on the Nashua River water-shed is much less than that on the water-sheds now in use, and less than upon any of the water-sheds nearer Boston, and will be reduced, as already indicated, by the construction of the proposed reservoir.

While the most dangerous impurities in a water are derived from the population upon the water-shed, a water may also take vegetable impurities from swamps and very shallow ponds and be thereby rendered less attractive, and, consequently, less suitable for water supply purposes. The color of water is a very good index of the amount of vegetable matter taken up in this way, and a comparison of sources with regard to color gives the results contained in the table on the next page.

The scale of colors is the one commonly used in analyses of water made by the State Board of Health, in which the higher colors are expressed by the higher numbers. Water as drawn in Boston during the year 1894 had an average color of 0.69 on this scale.

The table is divided into two parts, the first containing streams and small reservoirs which do not retain the water long enough to cause any considerable bleaching, and the other the ponds or large reservoirs in which the water remains much longer and has an opportunity to bleach.*

Streams or Small Reservoirs.

SOURCES.	Color.
Tributaries of Assabet River,	0.36
Swift River, at Belchertown,	0.38
Nashua River, above Clinton,	**0.40**
Deerfield River, above Shelburne Falls,	0.40
Stony Brook, at Cambridge dam,	0.71
Ware River, at Cold Brook,	0.75
Charles River, above South Natick,	0.86
Sudbury River,	0.87
Shawsheen River, at old Middlesex Canal crossing,	0.89
Saugus River, at Howlett's Dam,	1.16
Ipswich River, at Danvers,	1.36

Ponds or Large Reservoirs.

Lake Winnipiseogee,	0.01
Upper Mystic Lake,	0.11
Lake Cochituate,	0.22
Assawompsett Pond,	0.28
Fresh Pond, Cambridge,	0.30

In the first part of the table there are only two waters which have less color and another that has the same color as the water of the Nashua River, and all of these waters are from sources which may be used in the future to supplement the supply from the Nashua River. The second part of the table contains waters which have a low color

* Full analyses of these waters may be found in Appendix No. 5.

on account of the bleaching due to long storage. It is expected that the Nashua River water, after being improved by the drainage of the swamps upon the water-shed and after being bleached in the very large proposed reservoir, will have as little color as any of those given in the table, with the possible exception of Lake Winnipiseogee.

The tables show that the Nashua water is much better than the Sudbury, and the question naturally arises as to whether a thoroughly good water can be furnished by a combination of the two systems. For quite a long time in the future in dry years, and for a still longer time in years of average rainfall it will be feasible to take the whole water supply from the Nashua River and from the Stony Brook branch of the Sudbury River without including the flow of the main Sudbury River, which may be permitted to run to waste over the dam.

Nearly the whole of the city of Marlborough and the main village of Southborough are on the water-shed of Stony Brook; but, as already stated on page 17 of this report, a sewerage system has been constructed for diverting the sewage of Marlborough to a point outside of the water-shed, and the city of Boston has made plans and acquired land for filtering the water of the brook which takes the surface drainage from this city. This portion of the water-shed may be still further improved by the removal from it or purification of sewage and by the drainage of some large swamps; and it is believed that, with these improvements and the improvement which will result from the storage of the water in the large reservoir now being constructed by the city of Boston, the mingled waters will be nearly as good as water taken directly from the Nashua reservoir. If the water of the main Sudbury River is improved by the drainage of swamps and by other proper measures, it is quite probable that this water may be utilized in the future in connection with the water of the Nashua River even after the consumers have been educated by the introduction of the new supply from the Nashua River, so that they will demand a better water than at present.

Estimates of Cost. — In making the estimates given below it has been the aim to make them sufficiently liberal, and to include a large enough amount for contingencies to make them represent as nearly as possible the actual cost of the work when completed. It should also be borne in mind that the proposed aqueducts have been

designed of very large capacity, so that they will be capable of taking not only the water supplied by the Nashua River but also that to be supplied in the future from supplementary sources.

Estimates of Cost.

Reservoir on Nashua River, including the cost of land, buildings and water rights taken; the relocation of roads and railroads, the removal of all of the soil from the site of the reservoir, the construction of dams and dikes, and all incidental expenses, . . .	$9,105,000
Improvement of the water-sheds of the Nashua River and of the Stony Brook branch of the Sudbury River by the diversion and purification of sewage and drainage of swamps, ...	513,000
Aqueduct from the Nashua River to the Sudbury water-shed, and open channel from the end of the aqueduct to Reservoir No. 5, .	2,265,000
Additional 48 inch pipe from Dam No. 3 to Dam No. 1 and across the Rosemary valley, ...	78,800
Pumping stations, reservoirs and pipe systems for elevating and distributing water to all of the cities and towns in the metropolitan district, including the improvement of Spot Pond, ...	5,584,000
Damages for the diversion of water from the Nashua River, and incidental damages not included above, ...	1,500,000
Total first cost of proposed works for supplying water to *all* of the cities and towns in the metropolitan district, ...	$19,045,800

Time Required for Construction. — The present level of the Nashua River is such that as soon as the aqueduct from it to the Sudbury water-shed is completed the Nashua River water can be turned into Reservoir No. 5 and thence into Chestnut Hill Reservoir. While this aqueduct is being constructed the pumping station at Chestnut Hill Reservoir can be built, and the pipes extending from it to Spot Pond, and to many, if not all, of the cities and towns in the district, can be laid. The preliminary surveys and plans for these works have been carefully made, and the works are not so extensive but that if they were authorized by the Legislature of 1895 they should be ready for use in 1898. The construction of the reservoir on the Nashua River will take a longer time both on account of the magnitude of the work and the necessity for making more extensive borings at the site of the main dam before making the final location and designs.

Financial Statement.

In order to fully understand the significance of so large a sum as that given in the foregoing chapter as the estimated cost of the proposed metropolitan supply, it is well to make comparsions with other expenditures for similar purposes and with the revenues which are available for paying for the works; also to ascertain the yearly cost to a city or town or to each inhabitant for comparison with other annual expenses.

For this purpose I caused a careful compilation to be made of the total cost of the works in the metropolitan district at the end of each of the years from 1883 to 1893 inclusive, and of the net water-works debt of the whole district on the same dates. I have also caused the revenue from water rates and the cost of maintaining and operating the works to be ascertained.

In most of the cities and towns in the district where the water works are owned by the municipalities, the annual reports contain a carefully prepared statement from which the items above enumerated can be taken; but there are others in which the book-keeping is less carefully done, and it is difficult to separate the expenditures for maintenance and for construction and to determine what proportion of the total receipts are a revenue from the sale of water; moreover, the water companies publish no reports, and it is consequently impracticable to ascertain with regard to their works exactly the amount of the different items. It has therefore been necessary, where towns are supplied by water companies, to estimate the different items from the best information available; and where there were no other means of determining items, such as maintenance and revenue from water, it has been assumed that they are the same per inhabitant supplied as the average for all of the cities and towns in the district. As there were no water companies in 1883, and the population supplied by them has never exceeded 6.7 per cent. of the total population of the district, it will be seen that there might be considerable inaccuracy in the estimates for the towns supplied by them without seriously affecting the accuracy of the total for the whole district.

The aggregate cost of the water works of the district and the net water-works debt at the end of each of the years from 1883 to 1893, inclusive, is given in the following table: —

Total Cost and Net Debt of Water Works of the Metropolitan District at the End of Each Year from 1883 to 1893 inclusive.

YEAR.	Population.	Average Daily Consumption of Water (Gallons).	Total Cost of Works.	Net Debt.
1883,	–	–	$26,883,000	$16,537,000
1884,	653,493	40,150,000	28,008,000	16,504,000
1885,	688,047	42,931,000	29,904,000	17,014,000
1886,	729,718	46,046,000	31,284,000	17,399,000
1887,	759,958	50,683,000	32,146,000	17,847,000
1888,	789,094	55,554,000	33,392,000	17,790,000
1889,	816,408	54,260,000	34,539,000	17,806,000
1890,	848,012	58,060,000	36,206,000	18,574,000
1891,	887,384	64,200,000	37,489,000	18,393,000
1892,	924,344	70,315,000	39,069,000	18,399,000
1893,	957,085	79,555,000	40,505,000	18,655,000

From the above table we may deduce the following: —

Increase in total cost of works in ten years,	$13,622,000*
Increase in net debt in ten years,	2,118,000
Portion of increased cost of works paid for from revenue in ten years,	$11,504,000
Paid for from tax levy,	1,469,000
Balance paid from water-works revenue,	$10,035,000

* This sum may be divided into two parts, as follows: —

Works for obtaining water, including pumping stations and distributing reservoirs,	$6,857,000
Works for distributing water,	6,765,000
Total,	$13,622,000

The annual revenue from water rates and expenditure for maintenance of works, exclusive of interest and sinking fund payments, are shown in the following table: —

Revenue from Water Rates and Cost of Maintenance, Metropolitan District.

YEAR.	Revenue from Water Rates.	Cost of Maintenance.	Excess of Water Rates over Maintenance.
1883, ...	$1,970,000	$562,000	$1,408,000
1884, ...	2,011,000	601,000	1,410,000
1885, ...	2,145,000	605,000	1,540,000
1886, ...	2,191,000	650,000	1,541,000
1887, ...	2,315,000	688,000	1,627,000
1888, ...	2,456,000	797,000	1,659,000
1889, ...	2,537,000	733,000	1,804,000
1890, ...	2,617,000	724,000	1,893,000
1891, ...	2,758,000	836.000	1,922,000
1892, ...	2,822,000	801,000	2,021,000
1893, ...	3,123,000	872,000	2,251,000

The foregoing tables make a magnificent showing for the present financial condition of the water works of the metropolitan district. The statement deduced from the first table shows that during the ten years under consideration the net water works revenue paid $10,-035,000 toward the increase in cost of works during that period, and the second table shows the very large revenue from water rates and the rapid increase in revenue in comparison with the increase in cost of maintenance of works.

It would have been desirable to include in the second table the net interest, which is equivalent to the interest upon the gross debt less the interest upon the sinking funds; but it was not feasible to obtain the latter item from the published reports. There is no doubt, however, that the net interest has not increased much, if any, during the ten years, because the net debt has increased only one-eighth and the interest rate has been materially diminished by the payment of five and six per cent. bonds and by refunding these bonds at four per cent. The increase of $843,000 from 1883 to 1893 in the last column of the table, therefore, represents very nearly the increase in the net annual water-works revenue during these ten years; and if in every year from 1893 to 1903 there should be the same increase in net revenue over the corresponding year in the preceding decade, the amount which could be paid for new works in the

second decade without increasing the net debt would be the sum of $10,035,000 and $8,430,000, equal to $18,465,000.

These figures show that the metropolitan district by maintaining the present water rates could incur an expenditure of $18,465,000 for new works and pay for them, or for an equivalent amount of existing debt, very soon after their completion; or, if it should adopt what seems to be a more rational policy when the permanence of the works is considered, and pay for them at a less rapid rate, it would soon be in a position to materially reduce the water rates.

The following table contains additional statistics with regard to the present water works of the metropolitan district, and needs no explanation: —

Statistics relating to the Cost and Net Debt of the Water Works of the Metropolitan District, the Revenue from Water Rates, and the Payments for Maintenance and for Interest on the Gross Debt.

YEAR.	Total Cost of Works per Inhabitant.	Net Debt per Inhabitant.	Revenue from Water Rates.		Maintenance per Inhabitant.	Interest on Gross Debt per Inhabitant.
			Per Inhabitant.	Per Million Gallons.		
1883,	$42.79	$26.23	$3.14	$111.93	$0.90	$1.74
1884,	42.86	25.25	3.08	136.84	0.92	1.73
1885,	43.46	24.73	3.12	136.91	0.88	1.73
1886,	42.87	23.84	3.00	130.39	0.89	1.70
1887,	42.30	23.48	3.05	125.14	0.91	1.68
1888,	42.32	22.54	3.11	120.81	1.01	1.62
1889,	42.31	21.81	3.11	128.08	0.90	1.62
1890,	42.70	21.90	3.09	123.49	0.85	1.58
1891,	42.25	20.73	3.11	117.70	0.94	1.55
1892,	42.27	19.90	3.05	109.65	0.87	1.44
1893,	42.32	19.49	3.26	107.55	0.91	1.44

The fact that a large expenditure is well within the financial ability of any community does not prove the wisdom of the expenditure. In the case of a water supply this is to be determined by a comparison of different plans in regard to the quality of the water and the first cost and permanence of the works.

The proposed metropolitan water works are of unusually permanent character; and by this statement I mean not only that the works are to be built largely of masonry, which will endure for all time,

and of other permanent material, but they are designed upon a very liberal scale, so that they will not soon be outgrown, and the situation of the water-shed is such that it will be feasible to maintain the water in a pure condition for a very long time in the future. The pumping machinery, which is the most perishable part of the works, represents only a very small portion of their total cost. I do not see, therefore, why the works should not continue to have a large part of their original value after they have been in use for forty years; and, in making comparisons with other plans, I will reckon upon extinguishing the debt caused by the construction of these works in forty years.

The cost of the water works built from the proceeds of a loan is made up of three items; the annual interest, the sinking fund payments and the maintenance, the last item including all operating expenses, repairs and renewals.

For estimating the cost for interest and sinking fund we have the recent experience with the metropolitan sewerage forty-year three per cent. loan of $5,500,000, which has been sold at a premium, so that the amount realized has been $5,638,300.30. The sinking fund payments in this case are fixed by the metropolitan sewerage act at one-eightieth of the whole loan in each of the first ten years, one-sixtieth in each of the second ten years, one-thirtieth in each of the third ten years, and the remainder equally divided in the last ten years. The payments for interest and sinking fund together are, therefore, 4.25 per cent. of the amount of the loan in each of the first ten years. If, instead of reckoning the sinking fund in this way, it were to be reckoned upon equal payments every year for the whole forty years, and the money in the sinking fund were to net 3 per cent. interest, the annual payments would amount to 4.33 per cent.

If the total cost of the metropolitan water supply is assumed to be $19,000,000, the annual payments for the first ten years, upon the metropolitan sewerage basis, would be $807,500; and, as the estimated cost of maintaining the works is $260,000 per year, the total annual cost during the first ten years would be $1,067,500. The whole amount of money required for building the works would not be expended before the year 1900, at which time it is estimated that the population of the metropolitan district will be 1,148,033, and the annual cost per inhabitant at that time would therefore be ninety-three cents.

There are many reasons why the apportionment of the annual cost may not be made in direct proportion to the population of each municipality; but, as I could not at the present time reach a satisfactory solution of the question of apportionment, if I were to attempt it, I shall, in making comparisons in the next section, use the average annual payment of ninety-three cents per inhabitant.

Before leaving the financial consideration of the question I will refer to one other point; namely, that about one-fourth of the total cost of the proposed system has reference to work which relates to furnishing a water of good quality rather than to increasing the quantity. This work is the removal of soil and vegetable matter from the site of the reservoir, so as to prevent the water from taking up organic matter and thus promoting the growth of the minute organisms which give the water a disagreeable taste and odor; the building of the reservoir of extra large size, so that the water will be stored in it long enough to permit it to bleach and improve by the decomposition and disappearance of the organic matter; and the improving of the water-shed by the diversion and purification of sewage and manufacturing wastes, and by the drainage of swamps.

The amount of money which it is proposed to expend for these purposes is in the aggregate a very large sum, but the annual cost per inhabitant is small. In this instance it is not necessary to consider the item of maintenance, except to a very limited extent, because the cost of storing, conveying and distributing water is not increased because the water is of better quality. The cost, therefore, may be reckoned upon the interest and sinking fund only, and amounts to eighteen cents per year or four mills per week per inhabitant.

I believe there would be no question among water consumers as to the desirability of having the much better water when it can be supplied for so small an increase in cost.

A Statement with Regard to Each City and Town in the Metropolitan District as to whether it should enter the Metropolitan Water District or obtain its Supply from Independent Works.

The words "metropolitan district" have been defined and used in my report to include all of the towns within ten miles of the State House and the town of Swampscott, and the works have been

planned with reference to this district as a whole. In a previous chapter I have made a statement of the present condition of the water supply of each of these cities and towns and the opportunities for increasing the supply by independent action.

Now that the proposed plan for taking water from the Nashua River has been described, and a statement has been made of the average yearly cost per inhabitant for this supply, I propose to consider again the question of the future supply of each of the cities and towns, and to express my views as to whether it is for the interest of each of these communities to obtain its future supply by independent action or by becoming a part of the metropolitan water district.

The different places will be considered in the same order as in a previous section, that is, generally, in the order of their size, beginning with the largest place, but keeping together those which are supplied jointly from one system of works. So much has already been said with regard to the future water supply of these communities that in the case of many of them a very brief general statement will be sufficient. A reference to the pages of the report where the works are described will be given in each case.

Boston.

[A description of the water supply of this city may be found on pages 14-21.]

The city of Boston and the cities supplied by it consumed 42,173,000 gallons of water per day in 1890 and 56,858,000 gallons in 1894, and with the same increase in the next four years the consumption in 1898 will be 71,543,000 gallons. The total minimum capacity of its sources when the Sudbury water-shed is developed by the completion of Reservoir No. 5 will be 69,000,000 gallons per day. A comparison of these figures shows that the capacity of the Boston sources in a very dry year is likely to be reached or exceeded at the earliest date that a metropolitan water supply can be made available if the work is authorized by the Legislature of 1895, even if Mystic Lake, which both the State Board of Health and the Boston Water Board have agreed in condemning, is retained.

Admitting the need of immediate action with reference to obtaining an additional water supply for this city and the cities supplied by it, the only remaining question is as to whether this supply should be obtained by the independent action of the city of Boston or by

combining with the other cities and towns in the district. In determining this question the urgent needs of the other cities and towns should have great weight, because they cannot obtain by themselves a suitable water supply except at a large cost.

Viewing the matter from the stand-point of the city of Boston, it is also very desirable that the supply should be obtained for the whole district rather than for the city of Boston alone. If this city were obtaining an additional supply of water for itself, the best source from which to take the water would be the Nashua River: and, in order to take the water and improve its quality, it would be necessary to pay the full amount of damages for the diversion of the water and to build the same storage reservoir and make the same improvements upon the water-shed as are now proposed for the water supply of the whole district. There would be some saving by reducing the size of the aqueduct leading to the Sudbury water-shed and in constructing the pumping station at Chestnut Hill Reservoir, but the reduction in cost would be small in proportion to the reduction in capacity. There would of course be a very large saving in the cost of distributing the water throughout the metropolitan district; but, after making allowance for this, the cost would be much greater per inhabitant if the city of Boston were to introduce a supply from the Nashua River for itself than if the supply were introduced for the metropolitan district as a whole.

My conclusion, therefore, is that the city of Boston needs an additional water supply as soon as it can be obtained, and that it is for the best interests of the city, as well as of the other cities and towns in the metropolitan district, that this supply should be obtained by joint action.

Somerville, Chelsea and Everett.

[A description of the water supply of these cities may be found on pages 19–21.]

These cities own their distributing systems and purchase water from the city of Boston. The source of supply is Mystic Lake, and its safe capacity for supplying these places and the Charlestown district of Boston, or even for supplying these places alone, has already been exceeded. The inferior character of the water which this source furnishes has been referred to many times in this report.

The fact that these three places own their distributing systems and make annual payments for the water supplied to them renders their situation somewhat analagous to what it would be if they were

to become a part of the metropolitan water district. In accordance with a contract made with the city of Boston in 1886 this city furnishes the water and collects the water rates, including a fixed price for hydrant service, and pays back to the three cities one-half of the amount collected. The amounts paid by the three cities for water since 1890 are as follows: —

Amounts paid the City of Boston for Water supplied to Somerville, Chelsea and Everett from 1890 to 1894 inclusive.

YEAR.	Somerville.	Chelsea.	Everett.	Total.
1890, ...	$55,880	$35,600	$11,339	$102,819
1891, ...	60,151	36,447	12,974	109,572
1892, ...	77,641	42,635	17,448	137,724
1893, ...	76,185	45,803	19,817	141,805
1894, ...	83,401	46,764	22,420	152,585

The average annual cost of the metropolitan supply was estimated in the last section to be ninety-three cents per inhabitant, and upon this basis the annual payments for water in the years from 1890 to 1894 would have been as follows: —

YEAR.	Somerville.	Chelsea.	Everett.	Total.
1890, ...	$37,341	$25,955	$10,293	$73,589
1891, ...	39,587	26,691	11,697	77,975
1892, ...	42,009	27,435	13,339	82,783
1893, ...	44,834	28,214	14,945	87,993
1894, ...	46,879	28,631	15,801	91,311

It is probable that these cities, as they would not furnish any part of their supply from local sources and would not have any works to be utilized as a part of the metropolitan system, would pay more than the average rate per inhabitant in the whole district; but a comparison of the tables shows that they might pay much more than the average and yet pay less than is now paid to the city of Boston, and for the payment they would receive an ample supply of water

instead of one which may prove deficient in a dry year, and a pure water instead of a polluted one.

There are still other advantages to these cities in obtaining a supply from the proposed metropolitan system, as it provides for very large pipes running through the low-service districts of each of these places, and would therefore increase the pressures and obviate the necessity for laying additional supply mains for a very long time in the future; and in the high-service districts water would be furnished under ample pressure without the cost of operating local pumping stations.

Cambridge.

[A description of the water supply of this city may be found on pages 22–25.]

This city has already begun the construction of works for adding 6,000,000 gallons daily to its supply and for increasing the water pressure in the city. The prominent features of this plan, as described in the report of the Cambridge Water Board for the year 1894, are: —

1. The construction of a storage reservoir on Hobbs Brook.
2. The construction of a proposed distributing reservoir at Payson Park in Belmont.
3. The laying of two pipes from Fresh Pond to the distributing reservoir and from this reservoir to the city.
4. The erection of a new pumping engine.
5. The laying in 1899 of a duplicate pipe from Stony Brook to Fresh Pond.

The estimated cost of these works, as given in the report, is $1,215,000 when first completed, and $1,608,000 in 1899 after the duplicate pipe has been laid from Stony Brook to Fresh Pond. I will make a comparison of these works with the proposed metropolitan works in regard to annual cost, and the quality and quantity of water which they will supply. Taking the average annual cost of the metropolitan supply per inhabitant, as already given ($0.93), and the estimated population of Cambridge in 1900 (92,400), as given in Appendix No. 1, I obtain as the total annual cost $85,932.

The annual cost of the additional supply from Stony Brook is made up of interest, sinking fund and maintenance. The portion of the bonds already issued have thirty years to run, bear 4 per cent. interest and were sold at a premium of about $7\frac{1}{2}$ per cent. Making allowance for this premium, the interest rate may be considered $3\frac{3}{4}$

per cent. The bonds run for thirty years, and I will reckon the sinking fund for this time; although I believe that these works will not retain as large a proportion of their value at the end of thirty years as the metropolitan works at the end of forty years, for the reason that the distributing reservoir and the pipes leading to it will have comparatively little value when Cambridge takes a supply from the metropolitan works, and there is a serious question as to whether a water-shed as near Boston as that of Stony Brook will furnish a wholesome water thirty years hence.

By reckoning that the sinking fund will net 3 per cent. interest, as has already been assumed for the metropolitan sinking fund, I find that the annual payments to it should be 2.10 per cent., which, added to the 3.75 per cent. interest, makes 5.85 per cent. annually for interest and sinking fund, equal to $94,068. To this sum there should be added the cost of maintaining the storage reservoir and pumping the additional water supplied, which in the metropolitan system would be furnished under a sufficient pressure for use without local pumping.

The water which flows in the Nashua River under present conditions is better than the water which flows in Stony Brook. This is indicated by the following comparisons: —

	Nashua River.	Stony Brook.
Population per square mile,	69	107
Color of water on scale used in analyses of State Board of Health,	.40	.72
Excess of chlorine (parts per 100,000),	.07	.11
Organic matter as indicated by albuminoid ammonia (parts per 100,000): —		
Total,	.0168	.0246
Dissolved,	.0132	.0210
Suspended,	.0036	.0036

The water of the Nashua River is to be greatly improved by storage in a very large and thoroughly prepared reservoir and by improving the water-shed; while the water of Stony Brook is likely to deteriorate with the growth of population and the increase in

amount of market gardening upon the water-shed, owing to its proximity to Boston. If the Hobbs Brook reservoir were to be built in the manner originally proposed when a reservoir of 350 acres was contemplated, by removing all of the soil and vegetable matter from the site of the reservoir, the water stored in it would improve in quality by storage; but with the reservoir of 653 acres which is now contemplated, it is not feasible to make so thorough a preparation for the reception of water without greatly increasing the cost above the original estimate. Even if this reservoir were to be constructed in the best manner, it would receive the water from only about one-fourth of the water-shed of Stony Brook, and would be used to supply the city when the other portions of the water-shed did not furnish a sufficient quantity of water.

The average daily consumption of water per inhabitant in Cambridge in 1893 and 1894 was respectively 78 and 72 gallons, and in the whole metropolitan district 83 and 81 gallons, indicating that Cambridge uses about 7 gallons less per inhabitant than the average for the whole district.

The following table, giving the estimated future consumption of water in Cambridge, is obtained by deducting 7 gallons from the estimated future consumption per inhabitant in the metropolitan district, as given in a table on page 8, and multiplying the quantities thus obtained by the estimated future population of Cambridge, as given in Appendix No. 1.

Estimated Population and Daily Consumption of Water in Cambridge for Each Five Years from 1895 to 1930.

YEAR.	Estimated Population.	Daily Consumption per Inhabitant.	Total Daily Consumption.
1895, ...	80,917	78	6,312,000
1900, ...	92,400	83	7,669,000
1905, ...	104,720	87	9,111,000
1910, ...	117,880	90	10,609,000
1915, ...	131,880	92	12,134,000
1920, ...	146,720	93	13,645,000
1925, ...	162,400	93	15,103,000
1930, ...	178,900	93	16,638,000

The estimated capacity of the Cambridge sources as it is now proposed to develop them is 13,200,000 gallons per day, and by the estimate in the above table the consumption will equal this capacity in 1919.

This estimated capacity is upon the assumption that Cambridge may use the water of Stony Brook; although Waltham was authorized by chapter 257 of the Acts of 1884 to take water from this source, and the act authorizing Cambridge to take water from Stony Brook provides "that there shall be reserved from said waters sufficient for the town of Weston to supply itself and its inhabitants with pure water for the extinguishment of fires and for domestic and other purposes."

I have already indicated my belief that the cost of still further developing the Stony Brook source would be too great in proportion to the results to be obtained to warrant the expenditure.

The works proposed for the metropolitan supply include all that is necessary for supplying the whole metropolitan district with water until 1915, except an aqueduct from Reservoir No. 5 of the Boston Water Works to Weston and pipes leading from the end of the aqueduct into the metropolitan district. If enough of the local sources now used by cities and towns in the metropolitan district, other than the Sudbury and Cochituate sources of the city of Boston, were to be retained, to supply 20,000,000 gallons per day, the capacity of the proposed works would not be reached until 1919, which is the same year that the capacity of the Stony Brook supply would be reached, according to the above estimate; but the Nashua plan would have this advantage, that the works from this source to the metropolitan district are designed of sufficient capacity for future needs, and by the addition of tributaries of the Assabet River and the upper portion of the Ware River the supply could be increased at a comparatively small cost, so as to provide for more than the estimated population in 1930, even if all local supplies were then abandoned, and beyond the Ware River there are other sources from which a supply of excellent water could be obtained at a reasonable cost.

It may be said with regard to the above statements that the city of Cambridge is already committed to the development of the Stony Brook source and the increase of the water pressure in the city to the extent of having made contracts for the construction of a new pumping engine and the Payson Park distributing reservoir. It has

also taken land for the Hobbs Brook reservoir, and since Oct. 22, 1894, has had men at work clearing the site of this reservoir of trees and brush and removing soil. I am informed that the total amount of payments and of obligations incurred upon this work to date is about $538,000.

I believe, however, that if the Legislature of 1895 should authorize the construction of the metropolitan system and thereby make it practically certain that Cambridge would have an additional supply in a few years, it would be wiser for the city not to proceed with the construction of the Hobbs Brook basin, the duplicate pipe line from Stony Brook to Fresh Pond and some other parts of the proposed work, as there would still be a large saving in the annual cost for interest, sinking fund and maintenance, which would nearly offset any probable annual charge to Cambridge for a supply from the metropolitan works from which the city would obtain a better water and a more permanent supply.

This plan, which I believe would not be opposed to the best interests of the city of Cambridge, would be greatly to the advantage of the rest of the district, as the main pipes of the metropolitan system have to pass through Cambridge in any case, and its contribution to the metropolitan system would be much more than the cost of supplying it with water under the circumstances.

Lynn.

[A description of the water supply of this city may be found on pages 25-33.]

I have already stated so fully the present condition of the Lynn water supply and the difficulties in the way of obtaining a satisfactory additional supply that no further explanation is necessary. The amount of wholesome water which the present works of the city will furnish is not sufficient for present requirements, and an additional supply of good water is therefore needed. I have not been able to find any source from which this city can obtain any large additional supply of good water, and I have no doubt that it would be for the best interests of the city to obtain its supply from the metropolitan system. The situation of Lynn relative to the rest of the district, however, is such that it will cost more to supply it from the metropolitan system than other towns, and it may be questioned whether the amount that it would pay will more than offset the additional cost of supplying it with water. The decision, therefore, as to whether Lynn should be included in the water supply district,

should be settled wholly with reference to the interests of that city, and not with reference to the interests of the district as a whole.

Saugus.

[A description of the water supply of this town may be found on pages 25-33.]

This town owns and maintains its system of water pipes, but purchases water from the city of Lynn, which collects the water rates and pays to the town of Saugus 50 per cent. of the receipts. Before April 1, 1892, the amount paid to the town was $37\frac{1}{2}$ per cent. of the receipts. The amounts retained by the city of Lynn for supplying water to Saugus during the last seven years are as follows: —

1888,	$1,103	1892,	$2,326
1889,	1,424	1893,	2,407
1890,	1,797	1894,	2,621
1891,	2,161		

The cost of water from the metropolitan system in 1898, reckoned upon the average rate per inhabitant (93 cents) and the estimated population in that year (5,290), is $4,920.

If the city of Lynn were to take a water supply from the metropolitan district, there would be a 36-inch pipe passing through Saugus which would give it a practically unlimited supply of water. If this city should not take water from the district, a smaller pipe could be extended from one of the metropolitan mains to Saugus without excessive cost.

Taking into account the better quality and more ample quantity of water which the metropolitan supply will furnish, I believe it would be for the interests of the town of Saugus to take its water supply from the metropolitan works.

Newton.

[A description of the water supply of this city may be found on pages 33-35.]

This city has a ground-water supply of excellent quality, but, as already stated, the capacity of the present works in a dry year will be reached soon after the earliest date at which a metropolitan water supply can be introduced. The city, however, has already acquired a large area of land through which its collecting system may be extended, and it has been authorized by the Legislature to take from the Charles River or from the ground near it 5,000,000 gallons of water daily; but, should it succeed in obtaining this quantity of

water, the supply will only last, according to estimates given elsewhere, until the year 1908. An estimate of the cost of works for developing the ground-water supply indicates that it will be somewhat greater than for taking the additional supply from the metropolitan works; but if the water retains its present excellent quality it will be worth an extra price.

It is not probable that a supply of more than 5,000,000 gallons daily can be obtained from the ground unless measures are taken to facilitate the filtration of the river water into the ground, by pumping it upon porous land in the vicinity of the collecting system or by some other method.

The demands upon the summer flow of the river will be so great when the cities and towns now authorized to take water from it take all of the water to which they are entitled, that they should not be authorized to take a further quantity unless they compensate for the water taken by constructing storage reservoirs in some part of the water-shed above their works, which would add to the cost of developing the supplies beyond the limits at present authorized.

I am of the opinion that it is for the interests of the city of Newton to continue to utilize its present works as long as the water is of superior quality, and to develop the works if it shall be found that a further supply of water can be obtained in this way at a reasonable cost; but, in view of the comparatively short time that there is any certainty of obtaining a sufficient supply from the ground, and the uncertainty as to whether the water will remain good when much larger quantities filter into the ground from the river, I believe that the city should become a part of the metropolitan water district.

Malden.

[A description of the water supply of this city may be found on pages 35-37.]

This city will need an additional water supply at as early a date as it can be furnished by the metropolitan system. It has the right to take water from Martin's Pond in North Reading; but, as already stated on page 37, this pond in its present condition will not furnish a water of satisfactory quality, and it does not seem probable that it can be improved in such a way as to make it furnish a good water except at a prohibitory expense. There can hardly be a doubt that the annual cost of obtaining a water supply of inferior quality from this source would be as great or greater than for an ample supply of much better water from the metropolitan works.

There are other advantages in the metropolitan plan, as it provides for keeping Spot Pond full and for its improvement and maintenance. It also provides for very large pipes from Medford and Spot Pond to the centre of the city, and for furnishing water to both the high and low service under a pressure which will make local pumping unnecessary.

Waltham.

[A description of the water supply of this city may be found on pages 37–40.]

This city has a supply of ground water of excellent quality, which will probably be sufficient for the requirements of the city for ten or fifteen years after a metropolitan supply is introduced; and it now seems probable that the ground-water supply may be developed to furnish all of the water required until about the year 1920.

The city is at the present time authorized to take from the Charles River or the ground near it 3,000,000 gallons of water daily; and if it should be authorized to develop its ground water supply — most of which would be filtered river water — so as to take more than this quantity, it might be required to compensate for the water taken from the river by providing storage in some part of the water-shed of the river above its works.

The city is also authorized, by chapter 257 of the Acts of 1884, to take water from Stony Brook by paying the city of Cambridge a fair proportion of the amount expended by it for works and water damages; but it is not probable that a supply from this source would have any advantages over the metropolitan supply.

If the city of Waltham could be assured that its water would remain of as good quality as at present, with the much larger quantities which will be needed in the future filtering from the river into the ground, its works would have an advantage over the metropolitan system both in quality and cost; but with a very great uncertainty upon this point I think that it is desirable that some provision should be made by which this city could take water from the metropolitan system in the future, in the event of a failure of its own supply.

Quincy.

[A description of the water supply of this city may be found on pages 40, 41.]

This city is now in need of an additional supply of water, and may obtain a temporary supply to last until the metropolitan works are

in operation, or a more permanent supply from the Blue Hill River which would suffice until about the year 1921.

Upon estimating the cost of works for taking an independent supply from the Blue Hill River, as well as it was feasible to do so from the limited information available, but on a conservative basis, it was found that the yearly cost to Quincy for obtaining its water from the metropolitan supply was not likely to be more than two-thirds as much as for obtaining it from independent works, and the metropolitan supply would furnish a water of better quality.

Hyde Park.

[A description of the water supply of this town may be found on pages 41-43.]

I have already stated that the capacity of the source now supplying this town is limited, and that I believe that the water from this source will always be regarded with suspicion, so that it should be abandoned when a better supply can be obtained. The difficulties in the way of obtaining an independent supply are such that I have no doubt that the metropolitan supply will be the most available one for this town.

Milton.

[A description of the water supply of this town may be found on pages 41-43.]

This town is supplied by the Milton Water Company with water purchased from the Hyde Park Water Company, and, as indicated above under the head of Hyde Park, this source cannot be regarded as a suitable one for the future supply of the town either in the amount or quality of the water.

The Milton Water Company made investigations with regard to obtaining a ground-water supply near Pine Tree Brook in Milton, and they indicated that a water of excellent quality could be obtained from the ground at this place, and in sufficient quantity to supply as much water as the town would require for a few years, and possibly a much larger quantity. In view, however, of the uncertainties as to the quantity of water to be obtained from a ground-water source, the difficulty in maintaining the purity of a supply from a source so near Boston and the comparatively large cost of constructing and maintaining works for supplying a small community, I believe it would be better for the town of Milton to obtain its permanent supply from the metropolitan system.

Woburn.

[A description of the water supply of this city may be found on pages 43-46.]

As already stated, this city has a ground-water supply of excellent quality, but the capacity of the present source in a dry year has been so nearly reached that measures should be taken for increasing the supply. Various methods of doing this are mentioned on page 45, and it is also stated that Horn Pond, which from its proximity to the city and its large size might be thought of as a possible source, cannot be regarded as a safe one from which to take water for drinking purposes.

The plans which appear to be most feasible for increasing the water supply of this city have been very carefully considered, and the best information available has been utilized for making an estimate of their cost upon a very conservative basis, and of the quantity of water which they will supply. These estimates indicate that it will be cheaper for the city of Woburn to obtain its additional water supply from the metropolitan system than from independent works, and the metropolitan supply will be more ample in quantity and of better quality than any water which the city of Woburn is likely to obtain.

Wakefield and Stoneham.

[A description of the water supply of these towns may be found on pages 46-49.]

These towns are supplied with water by the Wakefield Water Company from Crystal Lake in Wakefield. The capacity of this source in a dry series of years has been reached, so that an additional supply is needed for one or both towns; and the water-shed from which the pond derives its supply is so near the thickly settled parts of these towns that the population upon it, which is already quite large, is likely to increase in the future to such an extent as to make the water of the pond unsuitable for drinking.

I do not know of any source from which an adequate quantity of good water can be obtained except the metropolitan system, and possibly some sandy land near the Saugus River within the water-shed now controlled by the city of Lynn. Even if the Wakefield Water Company or the towns supplied by it should obtain a right to take water from this place, I doubt if the additional water required could be obtained as cheaply as from the metropolitan system; and, taking into account the danger that before very many years Crystal Lake may have to be abandoned, I believe that it is for the interests of

PLAN No. 6.


STATE BOARD OF HEALTH
METROPOLITAN WATER SUPPLY.
MAP
SHOWING
PROPOSED WORKS FOR DISTRIBUTING WATER
IN THE
METROPOLITAN DISTRICT.
December 1894.
SCALE OF MILES.
FROM MAP OF BOSTON & VICINITY
COPYRIGHT 1894 by GEO. H. WALKER & CO. BOSTON
EXPLANATION
Low Service Works shown in red.
High " " " " blue.
Extra High " " " " green.
Pumping Stations for Metropolitan Supply thus:
Proposed Distributing Reservoirs and Tanks:
Existing " " "
Proposed Pipe lines thus:
Future Aqueducts and Pipe lines thus:
Existing Main Pipes thus:
Figures on Pipe lines give diameter in Inches
Limit of District which includes Cities and
Towns within Ten Miles of State House thus:
FUTURE AQUEDUCT
PROPOSED FUTURE PIPE LINE
READING
PEABODY
BEDFORD
BURLINGTON
WAKEFIELD
SAUGUS
SALEM
MARBLEHEAD
SWAMPSCOTT
LYNN
STONEHAM
MELROSE
WINCHESTER
LEXINGTON
MEDFORD
ARLINGTON
REVERE
NAHANT
WALTHAM
BELMONT
SOMERVILLE
CHELSEA
CAMBRIDGE
WINTHROP
WATERTOWN
BRIGHTON
NEWTON
BROOKLINE
NORFOLK
BOSTON
NEEDHAM
HYDE PARK
MILTON
PLYMOUTH
BRAINTREE
WEYMOUTH
HINGHAM
WRIGHT & POTTER PTG. CO., BOSTON. — GEO. H. WALKER & CO., LITH. BOSTON.

these towns that they should take water from the metropolitan supply as soon as it becomes available.

Brookline.

[A description of the water supply of this town may be found on pages 49–51.]

This town has a supply of ground water of excellent quality, which will probably be sufficient in quantity for the requirements of the town for about ten years after the introduction of a metropolitan supply, and it now seems probable that the ground-water supply may be developed so as to furnish all of the water required until about the year 1917.

The town is at the present time authorized to take from the Charles River 3,000,000 gallons of water daily; and, if it should wish to develop its ground-water supply beyond this limit, it might be required to compensate for the water taken by filtration from the river by providing storage in some part of the water-shed of the river above its works, which would obviously add to the cost of this development.

On account of the superior quality of the water now supplied from the Brookline works, I am of the opinion that the town should continue to use its own supply, and should develop it when an additional supply is needed if it can be done at a reasonable cost, as now seems probable; but, taking into account the uncertainty as to whether the water may not deteriorate with the continuous filtration of larger quantities from the river into the ground, and the difficulty which the town would have in obtaining a satisfactory independent supply if its present supply should fail in any way, I believe it to be for the interests of the town that provision should be made by which it may obtain an additional supply when needed from the metropolitan system.

Medford.

[A description of the water supply of this city may be found on pages 51–53.]

This city derives its water supply from Spot Pond and from an auxiliary source just south of the pond which it is now developing, and when developed it is estimated that the combined sources will furnish enough water to supply the city until 1899 or 1900, so that a further supply will be needed about as soon as a metropolitan supply can be introduced.

There is no source within my knowledge from which the city can obtain other than a temporary local supply of water, and the construction and maintenance of a supply of this kind is likely to cause

a greater annual charge than would be made for water from the metropolitan system.

Not only is water obtained from local sources likely to cost more than from the metropolitan system, but the introduction of water from this system will be of advantage to the city in other ways, as it would furnish an ample supply of pure water without the necessity on the part of the city of laying additional supply mains, and would furnish a high-service supply for the more elevated portions of the city from a large pipe passing near the centre of the city and College Hill without local pumping. It would also obviate the necessity for the construction of a permanent high-service pumping station and tank, and would keep Spot Pond full and relieve the city of all expense for its maintenance and for pumping water from it.

Revere and Winthrop.

[A description of the water supply of these towns may be found on pages 53-55.]

The situation of these two towns with reference to their water supply has already been so fully stated that I will only express the opinion that they will need a supply from the metropolitan system as soon as it can be made available.

Melrose.

[A description of the water supply of this town may be found on pages 55 and 56.]

As already indicated, this town will need more water as soon as a metropolitan supply can be made available; and in my opinion it is clearly for its interests to take water from the metropolitan system, rather than to attempt to develop any local sources. This town now purchases a part of its water from a private company at the rate of $7\frac{1}{2}$ cents per thousand gallons up to 300,000 gallons daily, and at a somewhat smaller rate for larger quantities. At $7\frac{1}{2}$ cents per thousand gallons, 280,000 gallons daily (the estimated capacity of the auxiliary source) would cost $7,665 per year, which the town would not have to pay after the introduction of a metropolitan supply. There would also be an additional saving, as the town would be at no further expense for the improvement and maintenance of Spot Pond.

Watertown and Belmont.

[A description of the water supply of these towns may be found on pages 57 and 58.]

The statements already made with regard to the water supply of these towns are so complete that I will only add my opinion that

they will need an additional supply of water soon, and that it can be obtained from the metropolitan system much more cheaply than by independent works.

Arlington.

[A description of the water supply of this town may be found on pages 58-60.]

This town has a very unsatisfactory water supply, on account of the poor quality of the water, and I know of no place where it can obtain a satisfactory independent supply at nearly as small cost as from the metropolitan system.

Winchester.

[A description of the water supply of this town may be found on pages 60-64.]

This town has three reservoirs, one of which contains a water of poor quality, owing to its being formed by flooding an extensive swamp, and another is becoming seriously polluted by the encroachments of the town of Stoneham upon its water-shed. It is feasible, however, to divert from this reservoir the water coming from the portion of the water-shed where the pollution occurs; and the town will then have two reservoirs fed from uninhabited water-sheds and containing water of good quality, which will furnish a supply to the town until about 1904; and it may be feasible for the town to maintain its supply for about six years longer by utilizing a part of the inferior water of the Middle Reservoir and by recovering and utilizing a part of the water which leaks past the dams.

On account of the comparatively short time to elapse before the town will need more water, and the impracticability of obtaining an independent supply at a reasonable cost, I believe it to be for the interests of this town to have a connection with the metropolitan water district, which will enable it to take water from the metropolitan system whenever it becomes desirable to do so.

Swampscott and Nahant.

[A description of the water supply of these towns may be found on pages 64 and 65.]

On account of the distance to these places from the central distributing points, the metropolitan supply could not well be furnished to them except in connection with the city of Lynn; but if the water were carried as far as Lynn, they could, on account of their situation relative to that city, be readily supplied. Both towns are now supplied with water by the Marblehead Water Company, and it will be difficult for this company or for the towns to maintain in

the future an adequate independent supply. I am therefore of the opinion that it will be for the interests of both of these towns to obtain water from the metropolitan system, if the works of this system should be extended as far as the city of Lynn.

Lexington.

[A description of the water supply of this town may be found on pages 65-67.]

Owing to the limited capacity of the present sources of supply, and the difficulties in the way of obtaining a satisfactory additional supply for this town from independent sources, I believe it will be for its interests to take water from the metropolitan water system whenever the existing supply proves insufficient.

Sources Investigated.

In addition to the Nashua River at Clinton and the present sources of water supply of the cities and towns in the metropolitan district, which have already been described, I have examined all of the larger sources in Massachusetts, east of the Berkshire Hills, and the more available sources in the States north of Massachusetts, in order to determine their relative value for the water supply of the metropolitan district. Next to the Nashua River above Clinton and the various sources which may be used to supplement it in the future, the Merrimack River above Lowell and Lake Winnipiseogee in New Hampshire seemed most worthy of careful investigation. The sources examined are given in the following lists: —

1. Sources not to be used in Connection with the Nashua River.

SOURCE.	Air-line Distance from State House (Miles).	Area of Watershed (Square Miles).
Merrimack River, above Lowell,	25	4,097
Merrimack River, above Lawrence,	25	4,634
Lake Winnipiseogee, New Hampshire,	77	360
Charles River, at South Natick,	15	156.3
Shawsheen River, at old Middlesex Canal crossing,	18	34.1
Ipswich River, at Danvers,	16	53.8
Ipswich River, at Topsfield,	19	96.7
Assawompsett and other ponds, in Lakeville,	36	62.1
Sebago Lake, Maine,	104	500

2. Sources which may be used in Connection with the Nashua River.

SOURCE.	Air-line Distance from State House (Miles).	Area of Water-shed (Square Miles).
Tributaries of Assabet River,	30	34.4
Ware River, at Cold Brook,	51	99.6
Ware River, near Gilbertville,	58	155.7
Swift River (dam at Belchertown),	64	185.7
Deerfield River, above Shelburne Falls,	89	454.4
Westfield River, middle and east branches, at Chester and Huntington,	93	179.4
Squannacook River and other tributaries of the Nashua from the west, in Groton and Shirley,	41	76.7

3. Sources which were found to be Unworthy of Extended Investigation.

Neponset River.
Taunton River.
Concord River.
Blackstone River.
Nashua River (north branch and main stream).
Quaboag River.
Miller's River.
Connecticut River.

1. Sources not to be used in Connection with the Nashua River.

Merrimack River.

This river approaches nearest the metropolitan district at a point between Lowell and Lawrence. It has a drainage area above the dam at Lowell of 4,097 square miles, and above the dam at Lawrence of 4,634 square miles. At either of these places it will furnish a practically unlimited supply of water for the metropolitan district, as its dry-weather flow is rarely if ever less than 1,000,000,000 gallons per day.

The places considered with reference to taking the water are above the thickly settled portions of the cities of Lowell and Lawrence. The point above Lowell is 1.4 miles more distant from the metropolitan district by the route selected than the point above Lawrence, but it has the advantage that the water is much less polluted, so that it is the most appropriate point upon the river from which to take the water.

If it were not for the cities and towns upon the banks of this river and its tributaries the water would be of good quality, although at times it is liable to be turbid and to have a high color.

The principal cities and towns upon the river above Lowell, with their populations in 1880 and 1890, are given in the following table: —

	Population in 1880.	Population in 1890.
Nashua, N. H.,	13,397	19,311
Manchester, N. H.,	32,630	44,126
Clinton, Mass.,	8,029	10,424
Concord, N. H.,	13,843	17,004
Leominster, Mass.,	5,772	7,269
Fitchburg, Mass.,	12,429	22,037
Franklin, N. H.,	3,265	4,085
Laconia, N. H.,	3,790	6,143
	93,155	130,399

Careful and extended investigations made by the State Board of Health at Lowell and Lawrence have shown that a very high death rate from typhoid fever has resulted from the use of the unpurified Merrimack River water.* In view of the dangerous character of the water when taken directly from the river, it is obvious that it should not be used for the water supply of the metropolitan district unless thoroughly purified.

The most feasible way of purifying a water like that of the Merrimack River is by filtering it through sand, a method which has been tested at the Experiment Station of the State Board of Health at Lawrence for many years, and has been in actual use for filtering the public water supply of this city for more than a year. At this place a sand filter (which is fully described in the annual report of the State Board of Health for 1893, pages 543–560) was completed and put in operation in September, 1893. It has an area of two and one-half acres, and consists of a bed of sand about five feet thick, through which water is filtered at a rate not exceeding 2,000,000 gallons per acre per day. The sand was very carefully selected, with a view to having its grains of such sizes that they would remove

* See annual reports of State Board of Health for 1890, pages 523–543; 1892, pages 667–704.

from the water the germs of typhoid fever. The practical results obtained with this filter have been very satisfactory indeed, as there has been a very great reduction in the death rate from typhoid fever and some other diseases in Lawrence since it was put in operation.

The principal features of the works planned for taking water from this river are: —

A pumping station on the banks of the river above Lowell, for raising the water about forty feet.

A masonry aqueduct, extending from Lowell to a point near Silver Lake Station in Wilmington.

Covered filter beds, near Silver Lake.

An aqueduct at a lower level, for conveying the filtered water to the easterly part of Woburn.

A pumping station, force main and short section of aqueduct, for lifting and conveying the water to Spot Pond.

The portions of the works capable of being enlarged, such as the pumping stations, force mains and filter beds, are designed for a safe daily capacity of 65,000,000 gallons; while those which cannot be enlarged, such as the aqueducts, are designed with reference to an average daily consumption of 200,000,000 gallons per day, and have a maximum capacity of 300,000,000 gallons per day.

A very favorable route was found for the aqueduct from the Merrimack River to the filter beds, but from the filter beds to East Woburn the conditions were less favorable.

The location near Silver Lake is well adapted to the construction of filter beds, as it is generally flat, and there is a large amount of sand of suitable quality for making the beds.

The study of the filtration of the Merrimack River water at this place was assigned to Mr. Allen Hazen; and two methods were considered, one of which proposed the filtration of the water into the natural ground and its collection by means of drain pipes or tubular wells; and the other the filtration of the water through artificial filter beds, such as are in use in many places in Europe and at Lawrence, Mass.

To filter by the first of these methods, a large area of land would be divided up into beds of convenient size, separated by embankments and made level by suitable grading. The water would be conveyed to these beds by a system of conduits and distributed over them, intermittently, to filter into the ground, from which it might be

taken by means of an elaborate system of driven wells connected with pumps or low-lying conduits, or by deeply laid drains. It is not often that extensive beds of porous sand can be found without occasional layers of finer and less pervious sand, which retard filtration: and this is one of the reasons why, in filtering water through natural sand beds, it is necessary to estimate upon a smaller quantity per acre than with artificial beds which are made of selected sand of nearly uniform grain. The necessities of the water supply of a great centre of population require that the supply should be furnished each day without the possibility of failure; and it is very doubtful if filtration could be carried on without interruption in the severe cold weather which sometimes occurs in this climate, without covering the area with a roof or making provision for flooding the beds with water to a considerable depth and filtering continuously during the cold weather.

The method of filtering through natural areas has advantages where large areas of entirely suitable land are available, because the cost of preparing the beds is comparatively small, and the slower rate of filtration will cause these filters to yield an effluent of greater chemical purity and less color than that from artificial filters operated at a higher rate. It was found, however, by surveys in the vicinity of Silver Lake, that, on account of intervening swamps and greater differences in the level of the surface than were noticeable when the territory was first reconnoitered, the natural filter beds would have to be scattered over a very large territory, and that the expense would probably be as great or greater than for artificial beds. The estimates have therefore been based upon the use of artificial beds; and, in order to prevent any question as to interference with their proper operation at any season of the year, provision was made for covering them.

In calculating the area of filter beds required it was assumed that the consumption of water would be at times one-third above the annual average, and that at such times the amount filtered per acre would be 2,570,000 gallons daily. With the average rate of consumption, this would leave one-fourth of the entire area out of use, or it would permit a lower rate of filtration to be used.

The estimates of first cost include 32 acres of filters, which are estimated to meet all requirements until 1905, and additional beds will be required from time to time, increasing the area to 90 acres in 1925. The estimates for the first cost of this plan are as follows: —

Estimate of First Cost of Works for taking Water from the Merrimack River at Lowell.

Pumping station at Lowell, for raising water 40 feet, and connections with river and aqueduct,	$879,000
Aqueduct 9.23 miles long, from Lowell to filter beds at Silver Lake, Wilmington, and all appurtenances, including connections from the end of the aqueduct to the filter beds,	2,410,000
Thirty-two acres of filter beds and appurtenances, and the main drain required for beds to be built subsequently,	2,180,000
Aqueduct 7.95 miles long, from filter beds to pumping station near Stoneham Branch Railroad in East Woburn, and all appurtenances,	2,202,000
Pumping station at East Woburn, for raising water 65 feet, and force main,	966,000
Aqueduct 0.82 of a mile long, from end of force main to Spot Pond,	191,000
Works for distributing water from Spot Pond to the cities and towns in the metropolitan district,	6,011,000
Total first cost of works, exclusive of damages for the diversion of water,	$14,839,000
Cost of operating filters and pumping stations at Lowell and East Woburn, capitalized at 5 per cent., and damages for the diversion of 65,000,000 gallons of water per day,	2,624,000
	$17,463,000

The capitalized cost of operating the filter beds and pumping stations has been added to this estimate, so that it may be compared with the cost of the Nashua plan, in which the water is not to be filtered and will reach the metropolitan district by gravity. The estimated first cost of this plan is, therefore, $17,463,000, or 8 per cent. less than the cost of the Nashua plan. In regard to the cost of future additions, the difference will not be large.

Of these two plans, I have no hesitation in recommending the one for taking water from the Nashua River, mainly because I believe that the small advantage which the Merrimack River plan has in regard to cost does not outweigh the disadvantage of taking a water which requires purification to make it suitable for drinking. Even if it were admitted that sand filtration with scientifically constructed filters and intelligent management will entirely remove disease germs from water, there is still the chance in the administration of a work of this kind that the preparation may be unscientific and the management unintelligent, which may cause the water to be either

imperfectly purified by filtration, or, by accident, carelessness or the necessity of maintaining the supply, sent to the metropolitan district without any filtration whatever. There is another objection to the Merrimack scheme which I regard as of importance, that there is a greater danger that the supply may be interrupted through some accident at the pumping stations or filter beds, or by a temporary failure of the supply of coal or of skilled labor required to operate the works.

Lake Winnipiseogee, New Hampshire.

With the exception of Moosehead Lake, this is the largest body of water in New England, and its immense size, together with the clear and colorless character of its water, has led to a popular belief that it might at some time prove to be the best source of water supply for Boston.

The distance from the State House in Boston in a direct line to the outlet of the lake is 84 miles, and to the head of Alton Bay, which is the part of the lake nearest to Boston, 77 miles. The surface of the lake is about 500 feet above mean sea level, so that it has sufficient height for furnishing water by gravity. The area of the lake is 70 square miles, and it has a water-shed, exclusive of the lake surface, of 290 square miles.

The lake can now be drawn down three or four feet below its ordinary high-water level. If the right could be obtained to draw the water of the lake down five feet below this level, and to take all of the water which the lake will furnish, it would supply 208,000,000 gallons of water per day in the driest year, which will be an ample supply of water for the metropolitan district for a long time in the future, — although not an inexhaustible supply, as the estimates already given on page 8 indicate that this amount of water may be required in 1922. Even if the metropolitan district should be granted the right to take water from this source, it is not at all probable that it would be permitted to take all of the water, because of the many important water powers supplied by it. Those at Lakeport and Laconia depend wholly upon the flow from this lake, which also furnishes nearly all of the water used by the water powers farther down the Winnipiseogee River at Tilton and Franklin Falls. At the last two places there are ten dams, utilizing a total fall of about 139 feet.

Lake Winnipiseogee not only furnishes very nearly all of the

water used upon the Winnipiseogee River, but it also has a very great value as a reservoir for maintaining during the summer the flow of the Merrimack River, on which are situated the three great water powers of Manchester, N. H., and Lowell and Lawrence, Mass., and other important powers.

If, on account of the restrictions which might be placed upon the amount of water to be taken from Lake Winnipiseogee, or on account of the future growth of the metropolitan district, the supply should prove insufficient, there is no serious engineering difficulty in supplementing the supply from this lake by turning into it, through a comparatively short tunnel, the waters of Squam Lake, which has an area of 11.7 square miles and a water-shed exclusive of the area of the lake of 48.7 square miles. It would also be possible, although involving a greater expense, to divert into Squam Lake the upper waters of the Pemigewasset River.

Samples of water were collected from Lake Winnipiseogee for analysis every month from June, 1887, to May, 1889, and the water was found to be practically colorless at all times, to be very soft, and to contain only a small amount of organic matter. The very excellent quality of the water is due largely to the excellent opportunity which it has in this great lake for bleaching and otherwise becoming purified by storage. Some of the streams entering the lake contain water which is far inferior to the water taken from the lake itself.

The permanent population upon the water-shed is 35 per square mile; but there is a large additional summer population. There are public water supplies at Weirs, Alton Bay, Wolfeborough and Meredith, and the hotels at other places have a supply of water brought to them in pipes. At Weirs and Alton Bay there are sewers which discharge directly into the lake, and I have no doubt that the same method of sewage disposal is used at other places where I did not make investigations.

With a view to ascertaining the cost of works for conveying water from Lake Winnipiseogee to the metropolitan district, all of the information to be obtained from existing maps and records was compiled, and a careful reconnoissance was made of the territory between Lake Winnipiseogee and Spot Pond. During this reconnoissance additional elevations were obtained at a great many points by simultaneous readings of two barometers, one being located at a station of known height and the other being read by the engineer in charge of the reconnoissance. From these examinations it was found

that a conduit could be built from Alton Bay to Spot Pond by a moderately direct route which would be much cheaper than if built from any other place upon the lake.

The conduit line finally adopted starts from a point near the shore of the lake, about three miles out from the head of Alton Bay. It is necessary to extend the conduit to at least this point, because the water at the head of the bay is polluted by sewage and discolored by the brownish water from the Merrymeeting River, which enters at this place. The topography of the country between Lake Winnipiseogee and Spot Pond is such that the water can be taken from the lake at Alton Bay with a comparatively small amount of tunnelling, and for eighteen miles support can be found for an aqueduct with a light grade. Beyond this point the land falls rapidly, and there are many low valleys to cross on the way to Spot Pond. It was found upon examination that it was either necessary to use pipes under pressure all of the way from this point to the pond, or to permit the water to fall about 160 feet in a comparatively short distance, so as to obtain support for a masonry aqueduct most of the way. The latter plan was found by estimates to be the cheaper one. The line adopted includes 52 miles of aqueduct, 13.4 miles of tunnel and 19.1 miles of pipe line, making a total of 84.5 miles.

The route selected passes through Alton, New Durham, Farmington, Strafford, Barrington, Nottingham, Epping, Fremont, Danville, Hampstead, Plaistow and Atkinson in New Hampshire: and Haverhill, Bradford, Boxford, North Andover, Andover, North Reading, Reading, Wakefield and Stoneham in Massachusetts.

The total estimated cost of works is as follows: —

Estimate of Cost of Works for taking Water from Lake Winnipiseogee.

65.4 miles of masonry aqueduct and tunnel, including inlet gatehouse and all other appurtenances and land damages,	$18,187,000
19.1 miles of steel pipe line, including bridges over Merrimack and other rivers, and all other appurtenances and land damages,	10,324,000
Works for elevating and distributing water through the metropolitan district,	6,011,000
Total, exclusive of water damages,	$34,522,000

The water damages would be very large, on account of the elevation of the lake, the large area of its water-shed, its value as a storage reservoir for maintaining the summer flow of the streams below it, and the importance of the water powers upon these streams.

The masonry aqueducts and tunnels for taking water from this lake are designed to be of the same size as those for taking water from the Nashua River; namely, to have a carrying capacity of 300,000,000 gallons per day when running full. The pipes across the valleys are designed to be of steel, 85 inches in diameter, and to be capable of carrying 100,000,000 gallons per day when one pipe is out of use; that is to say, when the hydraulic gradient is such that one pipe will carry 100,000,000 gallons, a second pipe is provided; and with a lower gradient, where two pipes are required to carry 100,000,000 gallons, a third pipe is provided.

There are difficulties in the way of obtaining a permanent right to take the water of this lake which are probably insurmountable; but, even if such a right could be obtained, I should not feel warranted in recommending this plan for adoption, when an ample supply of water, which would be but little if at all inferior in quality, can be obtained from the Nashua River and other portions of the high lands in the central part of Massachusetts at a much smaller cost.

Charles River.

The Charles River was carefully investigated as a source of water supply for the city of Boston in 1874. Plans and estimates were then made for taking water at several points along the river from Newton Lower Falls to a point a short distance above South Natick. The preference was given to the point above South Natick, and at the present time this is the best place for taking water from this river for the metropolitan district.

It was proposed to construct a dam at this place, raising the water 15 feet and flowing 3,915 acres (6.12 square miles) to an average depth of 9.08 feet. Surveys were also made for raising the water 6 feet higher, flowing a total area of 5,083 acres (7.94 square miles) and making the average depth of water 12 feet.

At the lower level the available capacity of the reservoir was estimated to be 9,000,000,000 gallons and at the higher level 18,000,000,000 gallons.

The area of the water-shed of the river above the site of the proposed dam is 156.3 square miles, and, with the available storage capacities above stated, should yield in the driest year respectively 63,000,000 and 93,000,000 gallons of water per day. The quantity of water available for water-supply purposes would be smaller, because it would be necessary to let much water flow past the dam

for the benefit of the cities and towns farther down the river, which take water from filter galleries or wells near the river, and to maintain the stream in proper sanitary condition as it flows through the middle of the metropolitan district. Not less than 20,000,000 gallons per day should be allowed to flow past this dam, and a larger flow is desirable. Assuming the amount to be 20,000,000 gallons per day, the quantities remaining for the water supply of the metropolitan district would be respectively 43,000,000 and 73,000,000 gallons. The larger of these quantities would not be likely to furnish a sufficient supply for the district after 1911.

The water of the Charles River compares unfavorably in quality with the water of the Nashua River, as will be seen by reference to the following table: —

	Charles.	Nashua.
Population per square mile of water-shed,	179	69
Color,	0.88	0.42
Residue on evaporation, total,	4.69	3.64
Loss on ignition,	1.83	1.16
Ammonia: —		
Free,	0.0010	0.0010
Albuminoid,	0.0251	0.0166
Excess of chlorine,	0.15	0.07
Hardness,	1.5	1.2

It will be seen by reference to the above table that the population per square mile of water-shed upon the Charles River is about two and a half times and the color of the water about twice as great as the corresponding figures for the Nashua, and that in the other chemical determinations the quantities relating to the Charles River are the larger ones. These figures, with the exception of the population per square mile, relate to the relative qualities of these waters as they flow in the streams; but, after storage in the reservoirs which it is feasible to construct in the two cases, there would be a much greater difference in the quality of the waters.

The reservoir on the Charles River would not only have a small depth, but would flow 3.2 square miles of wet meadows or swamps.

and it would be very costly if not impracticable to remove all of the mud from them, and if the mud and soil were not removed, there is little doubt that the water would contain abundant growths of the minute organisms which give water a disagreeable taste and odor.

No new estimates have been made of the cost of taking water from this source, and the old ones are not of much value, since they relate to taking a supply of only 50,000,000 gallons of water per day, and do not include the cost of removing the soil and mud from the bottom of the reservoir. It is probable that the cost of taking water from this source would be nearly if not fully as much in proportion to the quantity of water obtained as for taking water from the Nashua River; and, as the water would be far inferior in quality, and would be diverted from a stream where the water has a large value on account of the situation of the lower part of the stream relative to the metropolitan district and to the water supplies of several cities and towns in it, I believe it is not a source to be recommended for supplying water to the metropolitan district.

Shawsheen River.

The Shawsheen River has been brought to the attention of the public by several attempts on the part of the cities of Boston and Cambridge to obtain authority from the Legislature to take this river as a source of water supply. In all cases the point selected for taking the water has been at the crossing of the river by the old Middlesex Canal, and very near the main line of the Southern Division of the Boston & Maine Railroad.

Investigations of this source were first made by the city of Boston in 1874, and more extended investigations were made in 1886–87.

The drainage area above the proposed point of taking is 34.1 square miles. It was proposed to construct three reservoirs, having a total area of 1,270 acres and a total capacity of 4,000,000,000 gallons. The estimated cost of these reservoirs was $1,700,000, which included the removal of the soil and vegetable matter.

This source will furnish in the driest year 20,000,000 gallons of water per day, — a quantity which is less than the increase in the amount of water consumed in the metropolitan district from 1890 to 1894, and is obviously too small to furnish an additional supply for the whole metropolitan district for more than a very few years.

The Shawsheen River, therefore, needs to be considered further

only as a temporary source of supply for the whole district or as a permanent source for a small portion of the district.

The plan of works contemplated in 1874 and 1886 included the conveyance of the water from this river by an aqueduct to a pumping station in Winchester, and the raising of the water at this point to a reservoir of sufficient height to supply the low service district now proposed. The length of the aqueduct was ten and two-thirds miles, and the cost of the works to and including the reservoir was estimated to be $4,722,000, which includes the removal of soil from the site of the storage reservoirs. This amount is so large in proportion to the quantity of water to be obtained from this source that in my opinion it would be unwise to take the Shawsheen River either for the purpose of putting off the larger expenditure for an adequate water supply or for furnishing a supply to a part of the district from this source.

It was the general opinion from 1874 to 1887 that the water of the Shawsheen River was of satisfactory quality for the purposes of a public water supply; but the investigations of the State Board of Health since the latter year have shown that this is not the case. The population upon the water-shed (123 per square mile) is not very large, but the head waters of the stream are in the town of Lexington, within ten miles of the State House, where there is likely to be a large growth in the future, and the territory in and beyond Lexington is used to an increasing extent for market gardening. The water-shed also contains many swamps, from which the water acquires a high color and takes up much nitrogenous organic matter. The color of the water is more than twice as great as that of the Nashua River.

Ipswich River.

The lowest point at which it seemed desirable to consider the Ipswich River as a source of water supply for the metropolitan district is in the town of Topsfield, nearly opposite the main village, about half a mile below the point where a large tributary known by the name of Fish Brook enters from the north and above the point where the river flows through Wenham Swamp. At this point the river is 18.9 miles in a direct line from the State House, and it has a drainage area of 96.7 square miles.

A nearer point from which to take the water of the river is in the town of Danvers, about three-fourths of a mile from a line drawn across the river from the Danvers Insane Asylum to the main village

of Middleton. This point is 15.6 miles in a direct line from the State House, and the river above it has a drainage area of 53.8 square miles.

The river has a very slight fall, the total amount from its head waters to the lower point above referred to being only about 40 feet; and for this reason, and because of the general flatness of the territory for a considerable distance from the river, it would not be feasible to construct storage reservoirs without a large amount of shallow flowage. The population upon the water-shed is small, being nearly the same per square mile as upon the Nashua River, and the amount of manufacturing is also small.

The water-shed contains an unusually large proportion of swampy land, and as a result the water has a very much higher color and contains more nitrogenous organic matter than any other of the streams investigated in connection with the water supply of the metropolitan district. I would not recommend the use of this water without purification for water supply purposes.

Owing to the unfavorable opportunities for storing the water of spring freshets for summer use, the yield of this source would be very small in proportion to the size of the water-shed, probably less than 300,000 gallons per day per square mile. At this rate the total yield of the river at the upper and lower points respectively would be 16,000,000 and 29,000,000 gallons per day.

As the water of this river is of such poor quality as to require purification and the quantity of water is too small to furnish other than a very temporary additional supply for the metropolitan district, it is obviously undesirable to adopt this source for supplying the district as a whole. The possible use of the water of this river for supplying the city of Lynn has already been referred to on page 32.

Assawompsett and other Ponds in Lakeville.

There is a group of ponds lying south of Middleborough, mostly in the town of Lakeville, which are the largest bodies of fresh water in the State, and on account of their size they have sometimes been thought of as a possible source of water supply for Boston. The areas of these ponds are as follows: —

Assawompsett,	2,488 acres.	Little Quittacas,	320 acres.
Long,	1,804 "	Elder's,	145 "
Great Quittacas,	1,110 "		
		Total,	5,867 acres.

Assawompsett Pond is the lowest one of the series, and empties through the Nemasket into the Taunton River.

These ponds drain a swampy country, and are consequently fed by streams containing a very dark colored water; but, owing to their very great size, the water bleaches and is otherwise improved by storage so that when it flows out from Assawompsett Pond, which is the lowest one of the series, the water is of good quality.

The area of the combined water-sheds of these ponds is 50.4 square miles, including water surfaces, and 41.2 square miles, excluding water surfaces. A little more than a mile in a direct line below the point where Assawompsett Pond outlets into the Nemasket River there is a tributary known as Fall Brook which could be diverted into the pond. Including this brook, the total water-shed exclusive of water surfaces is 53.0 square miles.

These ponds are not very deep, and the shores have such gradual slopes that the water could not be drawn very low without uncovering large areas. If the ponds were to be raised, very large areas of boggy land would be flowed. It does not therefore seem probable that more than an average of 5 feet in depth could be made available for storage, and even this draft upon the storage might injuriously affect the quality of the water. With this amount of storage the yield of the ponds would be approximately 36,000,000 gallons per day in the driest periods.

The city of New Bedford now takes water from Little Quittacas Pond, and has the right to take water from Great Quittacas Pond. The city of Taunton takes water from Assawompsett and Elders ponds.

As this source is 35 miles from Boston, is at so low a level that the water would have to be pumped, and the topography of the territory between the ponds and the metropolitan district is not favorable to the cheap conveyance of the water, I have no question but that accurate surveys and estimates would show that water from this source would cost much more per million gallons than from other sources; moreover, the total quantity of water which this source will furnish is not enough for the metropolitan district for any long time, and if we look very far into the future it is not improbable that the cities now taking water from these sources and other cities in the southeasterly section of the State may require nearly all of the water which these ponds will furnish without making an excessive draft upon them.

Sebago Lake, Maine.

This lake is referred to because, with the exception of Winnipiseogee, it is the only great lake within about one hundred miles of Boston, and may therefore be thought of as a possible source of water supply for the metropolitan district.

The following comparisons are made between it and Lake Winnipiseogee: —

	Sebago Lake.*	Lake Winnipiseogee.
Distance from State House, Boston,	104	77
Area of water-shed including, water surfaces (square miles),	500	360
Area of lake,	50	70
Elevation above the sea,	251	500

* The statistics with regard to Sebago Lake are taken from the United States Census of Water Power, 1880, Part I.

Sebago Lake would furnish fully as much water as Lake Winnipiseogee, and, owing to its lower elevation, the amount of water damages would be less. On the other hand, on account of its lower elevation and the greater distance from Boston, works for taking water from it would be more costly, particularly if it should be found impracticable to convey the water to Boston by gravity.

The water supply of Portland, Me., is now taken from this lake. It has the same objection as Lake Winnipiseogee with regard to being situated outside of Massachusetts.

2. Sources which may be used to supplement the Supply from the Nashua River.

Tributaries of the Assabet River.

The aqueduct from the Nashua River to the Sudbury water-shed crosses the Assabet River about three-fourths of a mile below the village of Northborough, but at this point the river is below the level of the aqueduct; moreover, owing to the polluting matters which enter the stream at Northborough, to the very large area of swampy land along the river between Northborough and the Boston & Albany Railroad, and to the disposal of the sewage of West-

borough upon the banks of this section of the river, the water at the aqueduct crossing is not of suitable quality for water supply purposes.

The portion of the river above the Boston & Albany Railroad and portions of the tributaries of the river from the west drain a total area of 34.4 square miles, containing a population of only 60 per square mile. These tributaries, including the upper waters of the main river, can be diverted either into the aqueduct or into the upper end of the Sudbury water-shed by gravity. One of the more important tributaries passes directly over the tunnel on the line of the aqueduct, and the water can be diverted into the tunnel by making an opening into it; and others are so situated as to require only a short connecting pipe to divert their waters into the aqueduct. The upper waters of the river can be diverted into one of the feeders of Reservoir No. 5 by a small aqueduct two and one-half miles long.

The water of these streams as a whole is as good as the water of the Nashua River, and, although they would not have the advantage of storage in the Nashua reservoir, they would be stored in Reservoir No. 5.

In view of the fact that this water need be used only if the Nashua reservoir should not fill in the spring, I think it probable that this will prove to be the best source for first supplementing the Nashua River supply.

No surveys have been made as a basis for estimating the cost of obtaining these waters; but estimates made from the best information available indicate that the total cost would not exceed $600,000, exclusive of damages for the diversion of water; and the available yield would be increased about 28,000,000 gallons per day, making the total daily capacity of the metropolitan sources 201,000,000 gallons.

Ware River.

As will be seen by reference to Plan No. 3, the Ware River water-shed lies directly west of that of the Nashua River, and the divide between the two is also the divide between the streams running easterly toward the Atlantic Ocean and those running westerly to the Connecticut River. At Cold Brook, a village in the towns of Oakham and Barre, where the Ware River has a water-shed of 99.6 square miles, the river is 645 feet above the level of high tide and 145 feet higher than Lake Winnipiseogee. At this point there is an extremely favorable location for a reservoir, and from it a tunnel 8.72

miles long can be constructed to convey the water to a point on the Quinepoxet River, which is 15 feet lower than the Ware River at Cold Brook, thence to flow down the Quinepoxet River into the proposed Nashua River reservoir.

The water-shed of the Ware River above Cold Brook is hilly, contains a very small population (32 per square mile), and the factories and mills upon it are small and not of a character to produce objectionable wastes. From a sanitary point of view, therefore, this water-shed is very favorable indeed, but there are some large swamps upon it, in which the water acquires a brownish color, and they would have to be drained in order to make the quality of the water entirely satisfactory.

The reservoir will be formed by building a masonry dam across the river, a short distance below the village of Cold Brook, at a point where the distance across the valley 70 feet above the level of the stream is only 785 feet. This dam would flow an area of 1,035 acres (1.62 square miles) to an average depth of 33 feet. The site is an extremely favorable one for a reservoir, as there is scarcely any swampy land within its limits and no shallow flowage. The village of Cold Brook, which contains 31 houses, would be flooded, and a portion of the Ware River branch of the Boston & Albany Railroad, but this railroad could be located at a higher level without much difficulty.

The length of the tunnel from Cold Brook to the Nashua River has been carefully determined, and it is estimated to cost $3,600,000. The entire cost of the reservoir, including the land taken, the construction of the dam, the relocation of the railroad and the removal of all soil, would be approximately $2,000,000. If $500,000 more are allowed for the cost of improving the water-shed, the total cost for adding the upper portion of the Ware River, exclusive of water damages, will amount to $6,100,000.

As the head of the tunnel may be located below the level of the Ware River, a large portion of the water of the stream could be diverted into the Nashua water-shed without constructing the reservoir, and its construction might, therefore, be deferred for many years. If the upper Ware River is added after the tributaries of the Assabet to the other metropolitan sources, it will increase the daily supply 71,000,000 gallons, making the total daily capacity 272,000,000 gallons.

About nine miles farther down the Ware River, and only a short

distance above Gilbertville, there is an additional area of water-shed of 56.1 square miles, which is hilly and contains a population of only 54 per square mile. At this point the elevation of the river above high tide is 534 feet, and the water could be turned into a proposed tunnel, which will be described subsequently, running from the Swift to the Nashua River.

Swift River.

The Swift River lies west of the Ware River, and at a point below Enfield, where the river is 376 feet above high tide, there is a favorable location for a dam. The river at this point drains an area of 185.7 square miles, containing a population of only 30 per square mile. The water-shed contains few swamps, and the water has a light color and is of excellent quality. The river is made up of three branches, and the topography is remarkable, as, notwithstanding the hilly and almost mountainous character of the water-shed, the streams have very little fall and the valleys are wide, so that it is possible by the construction of a main dam 2,470 feet long, raising the water 144 feet above the present level of the river, and of a secondary dam 2,065 feet long and 114 feet high, to flood an area of 36.9 square miles, forming a reservoir which will hold 406,000,000,000 gallons of water and have an average depth of water of 53 feet. It is difficult to comprehend an enormous figure like that indicating the capacity of this reservoir; but its relation to the water supply of the metropolitan district may be understood from the statement that the reservoir when full would supply the district at the present rate of consumption of water for thirteen years if no water flowed into the reservoir during the time.

The reservoir would have a length of 17 miles and a maximum width of 3.9 miles, and would in fact be an artificial lake half as large as Lake Winnipiseogee, containing several mountainous islands. The high-water level in this reservoir is 520 feet above high-tide, and consequently 135 feet above the high-water level in the proposed Nashua reservoir.

For conveying water to the Nashua reservoir a tunnel is proposed upon the line indicated upon Plan No. 3, and with the grade shown upon the profile given in connection with that plan. The total length of the tunnel is 27.66 miles. Its upper end is 75 feet below the high-water mark in the Swift River reservoir, and its inclination about one in 2,100. The tunnel from the upper Ware River to the

Nashua might be constructed so as to form a part of this tunnel by placing it at the proper level, as indicated upon the profile, and building a shaft at each end through which the water could enter and leave the tunnel. If this were done, the additional length of tunnel required to reach the Swift River would be 18.94 miles.

The addition of the lower Ware and the Swift River would increase the daily capacity of the metropolitan sources 200,000,000 gallons, making a total capacity of 472,000,000 gallons per day.

The distance in a direct line from the Swift River Reservoir to the State House is 64 miles; but, owing to the utilization of natural channels, only 50 miles of artificial channel are required to convey the water to the terminus of the aqueduct in Weston, notwithstanding the indirect course which such channels necessarily take. This distance is 34.5 miles less than the length of the conduit from Lake Winnipiseogee to Spot Pond.

Deerfield River.

The Deerfield River takes its rise in Vermont, and flows easterly through the north-westerly portion of Massachusetts into the Connecticut River. In order to obtain water from it by gravity and beyond the danger of pollution, it will be necessary to take the water at a point above Shelburne Falls, 89 miles in an air line from the State House. At this point the river is, according to the topographical survey of the State, 460 feet above tide water; and it seems probable that a reservoir could be constructed by damming the river, which would be high enough above the level of the Swift River Reservoir so that water could be turned into the latter by gravity. There are several streams which unite in Colrain to form the North River, a tributary of the Deerfield, and which are high enough so that they could be diverted into the proposed reservoir above Shelburne Falls. The water-shed of the Deerfield River, including these streams, is 454.4 square miles.

The water of the river is of very good quality.* The population upon the water-shed is only 21 per square mile. The color of the water is the same as that of the Nashua and more than that of the Swift.

The Deerfield River is so far from Boston that it is obviously an undesirable source of supply for the metropolitan district, except in

* Analyses of the water of this river are given in Appendix No. 5.

connection with the Swift River, if that source should ever need to be supplemented. The distance from the Deerfield River above Shelburne Falls to the upper end of the Swift River Reservoir is 24 miles.

Westfield River.

The Middle and East branches of the Westfield River at Chester and Huntington drain a mountainous territory of 179.4 square miles, which contains only 21 inhabitants per square mile. At the points referred to these streams are of such a height that their waters could be diverted by gravity into the Swift River Reservoir. The distance, however, to this reservoir is somewhat greater than from the Deerfield River. The Westfield River is so far from Boston (93 miles) that it obviously does not need to be considered except as a possible supplementary source of supply in the far distant future.

The Squannacook River and Other Tributaries of the Nashua from the West in Townsend and Shirley.

The Squannacook River takes its rise in New Hampshire, and flows in a south-easterly direction through Townsend and between the towns of Groton and Shirley into the Nashua River. Judging from the topographical map of the State, it would be feasible to divert the water of several streams, of which the Squannacook is the most important, having a total water-shed of 76.7 square miles, by means of an aqueduct about 25 miles long, into the head of the aqueduct leading from the Nashua River to the Sudbury water-shed; and an additional area of water-shed of about 25 square miles might be added by pumping the water.

It seemed so obvious that these sources were inferior to others for supplementing the supply from the Nashua River, that no extended investigation of them was made.

3. Sources which were known to be Unworthy of Extended Investigation.

It is unnecessary to refer to these in detail.

The Neponset and Blackstone rivers are well known as streams which are too much polluted to be of any value for water-supply purposes.

The North Branch of the Nashua River has the city of Fitchburg and the town of Leominster near its upper end, and is seriously pol-

luted. The main stream also is affected by this pollution and the additional polluting matter contributed by the town of Clinton.

The Taunton River has near its head waters the city of Brockton and the towns of Abington, Whitman, East Bridgewater, Bridgewater and Easton, and is unsuitable for water-supply purposes, both on account of the polluting matter which enters it from these places and the swampy character of its water-shed.

The Concord River receives polluting matter from Northborough, Hudson and Maynard upon the Assabet River and from Saxonville upon the Sudbury River. The sewage-disposal areas of Marlborough and Framingham are also located upon tributaries of the Sudbury River. The Sudbury and Concord are noted for the vast area of wet meadows along their course from Wayland to Billerica.

Both the Quaboag River, which runs westerly near the line of the Boston & Albany Railroad, and the Miller's River, which has a corresponding relation to the Fitchburg Railroad, have large towns near their head waters, and other towns and factories at frequent intervals along them.

The Connecticut River is both a polluted and a silt-bearing stream, and is so far from Boston that it obviously compares unfavorably with the Merrimack River as a source of water supply for the metropolitan district.

Water Supply of Cities and Towns in and near the Nashua Water-shed.

The act under which the investigations for a water supply for the metropolitan district have been made requires the State Board of Health to investigate, consider and report, not only with reference to the water supply of the metropolitan district, but of other cities and towns which in its opinion should be included in connection therewith. It is obvious that the taking of a large water-shed for the water supply of the metropolitan district may have an influence upon the present or future water supplies of the cities and towns in and near the water-shed.

The town of Clinton obtains its supply at the present time from Wekepeke Brook in the town of Sterling, and in 1892 obtained authority from the Legislature to take the water of Waushacum Lake in the town of Sterling, which is within the water-shed of the Nashua River above the proposed dam. This town now has authority to take enough water to supply it for a long time in the future, and its

water supply needs no further consideration at present. The town of Lancaster obtains its water supply from the Clinton water works, and should, therefore, receive the same consideration as Clinton.

Of the towns within the water-shed, I see no reason why they should not all be permitted to take water from any appropriate source within it as freely as if the water-shed were not taken for the water supply of the metropolitan district.

The city of Worcester is situated only about five miles from the southerly boundary of the Nashua water-shed, and its water supply is taken by gravity from two comparatively small sources west and north-west of the city. One of these, known as the Lynde Brook source, supplies all of the water for the high service and a part of the water for the low service; while the other, known as the Tatnuck Brook or Holden source, supplies the low service only. The Lynde Brook Reservoir has been exhausted this year by the draught upon it, and a temporary supplementary supply has been obtained from a stream in its vicinity know as Kettle Brook. The city of Worcester petitioned the Legislature Jan. 28, 1895, for authority to take permanently the waters of this brook.

While this addition to the water supply is an important one, further additions will be necessary before many years, and the most obvious source from which to obtain this supply is Asneybumskeit Brook, one of the tributaries of the Nashua River above the proposed dam.

As it is undesirable that the city of Worcester should take any of the water from the Nashua water-shed if another source equally or nearly as good could be found, I caused careful examinations to be made of all of the sources within a reasonable distance of the city of Worcester. Samples of water from these sources were analyzed, their elevations were determined from the State map and by the use of a barometer, and their capacities were estimated as well as practicable from the best information obtainable without making actual surveys.

As a result of all of these examinations, it became evident that a portion of the Nashua River water-shed, having an area of 9.49 square miles, from which the water could be diverted into the Holden Reservoir by gravity, would be the most appropriate source from which to take a further additional supply for the city of Worcester when the capacity of its other sources was reached. This area is

indicated upon Plan No. 4, and marked "Area recommended for Worcester water supply."

In the estimates which have been given of the capacity of the Nashua River source I have not deducted anything for the amount of water which might be taken from the water-shed by the city of Worcester. If this city should take all of the water from the portion of the water-shed above indicated, the daily capacity of the Nashua River source would be reduced 8,500,000; but if a part of the water of the spring freshets should continue to flow down into the Nashua Reservoir, the reduction would be less. In any case the taking of this water by Worcester would not prevent the metropolitan district from obtaining a sufficient supply of water, although it might require the addition of the tributaries of the Assabet River or the Ware River at a somewhat earlier date than would otherwise be necessary.

The town of Leicester is situated just west of the city of Worcester, and its water supply is now taken by gravity from the head waters of Kettle Brook, only a short distance from Asneybumskeit Pond, in which Asneybumskeit Brook takes its rise. When the Leicester water works were first constructed this pond was regarded as a possible source for obtaining a supplementary supply in the future; and, on account of its situation, I regard it as an appropriate source for this purpose.

I do not know of any other cities or towns near the Nashua water-shed which have any claim upon its waters.

I recommend that reservations be made in the metropolitan water act which will permit the towns of Clinton, Lancaster, Sterling, Boylston, West Boylston, Holden, Rutland, Princeton, Paxton and Leicester and the city of Worcester to take water from the Nashua River water-shed when authorized to do so by the Legislature.

Detailed Description of Proposed Plan for taking an Additional Water Supply from the Nashua River.

The Water-shed and its Improvement.

The map of the Nashua River water-shed contained in this report (Plan No. 4) is based mainly upon the recent topographical map of the State; but the results of careful surveys of the proposed reservoir and of the Quinepoxet River, from the reservoir up to a point near Ruralville, where the proposed future tunnel from the Ware River will empty, have also been utilized. The boundary of the

water-shed was reconnoitered for its whole length, and carefully located upon the State map. Every part of the water-shed has been visited, and all of the swamps, ponds and reservoirs have been located with care.

Sanitary statistics have been obtained with regard to all of the mills and villages upon the water-shed, and are given in Appendix No. 7.

Many analyses have been made of samples of water from streams and ponds in different parts of the water-shed, and the color of the water of every brook of considerable size has been determined and tabulated.

Using the results of the examinations above indicated as a basis, plans have been devised for improving the character of the water flowing in the streams and for preventing its pollution. The greater part of the water-shed contains no mills which produce objectionable wastes, or villages of more than 100 inhabitants; but, near the head of the proposed reservoir and upon the Quinepoxet River and its branches, not more than five miles in a direct line from the head of the reservoir, there are several manufacturing villages from which it is proposed to lay sewers which will unite in one main sewer running down the valley of the Quinepoxet River to a sewage disposal field near Oakdale. The upper ends of these sewers are to be located at Chaffinville, Holden, Eagleville and Ruralville, and the sewers are intended to take the sewage from any public sewers that may be constructed in these villages or the villages below them, and the sewage and more objectionable portion of the manufacturing wastes from the various mills. Four of the mills next above Oakdale and the villages of Oakdale and Boylston Common are at too low a level to permit the discharge of the sewage and manufacturing wastes from them upon the disposal area by gravity; and it is therefore proposed to provide a pumping station near Oakdale to pump the sewage and wastes from these places to this area.

In order to further improve the quality of the water entering the reservoir, it is proposed to drain the swamps upon the water-shed so that the water will not stand in or upon them, and to clean out or drain certain shallow millponds which unfavorably affect the quality of the water passing through them.

It is estimated that the work which has been indicated and some other miscellaneous items of work incidental to the sanitary protection of the water-shed will cost $450,000.

Statistics relating to the Nashua River Water-shed.

Area of water-shed (square miles), ... 118.23
Elevation of highest point in water-shed above sea level (feet), . . 2,002

	Including Reservoir Site.	Excluding Reservoir Site.
Estimated population upon water-shed in 1894, .	8,188	6,477
Population per square mile of water-shed, . .	69	58
Number of villages containing a population of more than 100, ...	10	9
Population of these villages, ...	4,446	2,979
Farming and scattered population, ...	3,742	3,498
Area of swamps (acres), ...	2,322	2,300
Area of swamps (square miles), ...	3.63	3.59
Area of existing ponds and reservoirs (acres), . .	1,402	1,223
Area of existing ponds and reservoirs (square miles),	2.19	1.91

Nashua Storage Reservoir.

As already stated, the proposed reservoir will be created by building a dam across the Nashua River in the town of Clinton, and by constructing certain dikes to prevent the water from overflowing in other directions. A survey was made in much detail of the whole territory to be flowed, and a large map has been prepared with contours every five feet, from which the capacity and area of the reservoir at different levels, as given in the following table, have been deduced: —

Area and Capacity of Proposed Nashua River Reservoir at Different Elevations.

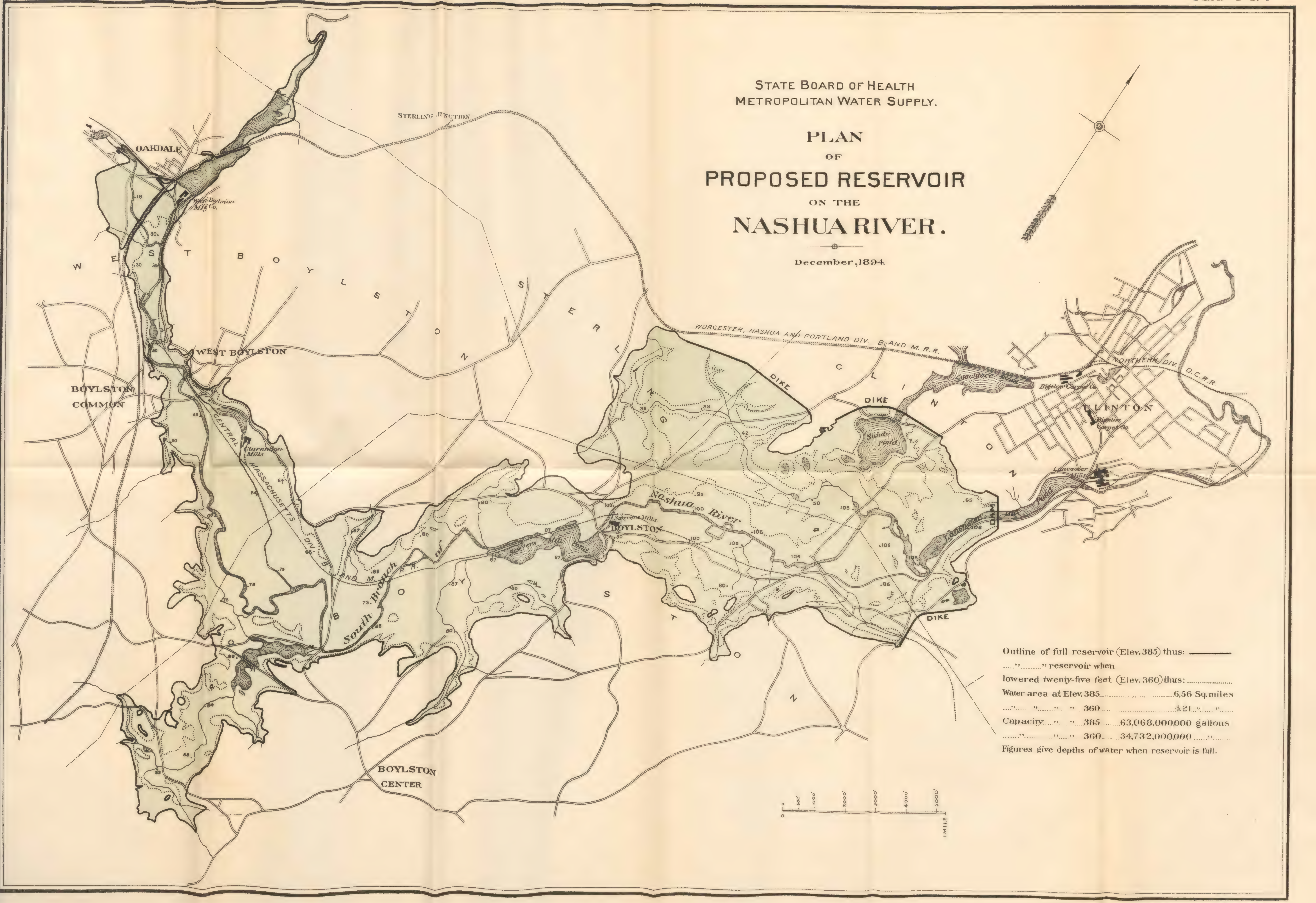
Elevations above Boston Water Works Base (Feet).	Area.			Total Capacity below Elevation, given in First Column (Gallons).	Capacity in the First Five Feet below Elevation, given in First Column (Gallons).
	Square Feet.	Acres.	Square Miles.		
260	18,000	–	–	–	–
265	155,000	4	.01	3,231,000	3,231,000
270	419,000	10	.02	13,969,000	10,738,000
275	1,154,000	26	.04	43,388,000	29,419,000
280	4,622,000	106	.17	151,403,000	108,015,000

Area and Capacity of Proposed Nashua River Reservoir at Different Elevations — Concluded.

Elevations above Boston Water Works Base (Feet).	Area.			Total Capacity below Elevation, given in First Column (Gallons).	Capacity in the First Five Feet below Elevation, given in First Column (Gallons).
	Square Feet.	Acres.	Square Miles.		
285	9,194,000	211	.33	409,777,000	258,374,000
290	13,711,000	315	.49	838,100,000	428,323,000
295	17,057,000	392	.61	1,413,451,000	575,351,000
300	24,907,000	572	.89	2,198,166,000	784,715,000
305	34,502,000	792	1.24	3,309,098,000	1,110,932,000
310	41,396,000	950	1.48	4,728,389,000	1,419,291,000
315	49,648,000	1,140	1.78	6,430,911,000	1,702,522,000
320	60,186,000	1,382	2.16	8,465,540,000	2,034,629,000
325	67,721,000	1,555	2.43	10,876,674,000	2,411,133,000
330	75,222,000	1,727	2.70	13,549,715,000	2,673,041,000
335	81,935,000	1,881	2.94	16,488,553,000	2,938,838,000
340	87,010,000	1,997	3.12	19,647,830,000	3,159,277,000
345	92,764,000	2,130	3.33	23,009,606,000	3,361,776,000
350	99,713,000	2,289	3.58	26,608,920,000	3,599,314,000
355	108,590,000	2,493	3.90	30,504,190,000	3,895,270,000
360	117,469,000	2,697	4.21	34,731,499,000	4,227,309,000
365	127,800,000	2,934	4.58	39,318,027,000	4,586,528,000
370	145,640,000	3,343	5.22	44,431,351,000	5,113,324,000
375	160,356,000	3,681	5.75	50,173,467,000	5,722,116,000
380	173,761,000	3,989	6.23	56,401,453,000	6,247,986,000
385	182,720,000	4,195	6.56	63,067,648,000	6,666,195,000

The reservoir is shown in considerable detail by Plan No. 7. A dotted line within the reservoir indicates a depth of 25 feet below the full reservoir, and figures indicate the depths at many other points.

The shores of the reservoir are as a rule very abrupt, but in the northerly half of the lower portion of the reservoir there is a considerable area of elevated sandy land which will be covered with water to a depth of only about 15 feet. For a distance of $2\frac{1}{2}$ miles up stream from the main dam the depth of water near the present river channel will equal or exceed 100 feet. In the next 3 miles it will be between 55 and 100 feet, and a depth of from 30 to 50 feet is found very nearly up to the head of the reservoir.


STATE BOARD OF HEALTH
METROPOLITAN WATER SUPPLY.
PLAN
OF
PROPOSED RESERVOIR
ON THE
NASHUA RIVER.
December, 1894.
OAKDALE
West Boylston Mfg. Co.
WEST BOYLSTON
BOYLSTON COMMON
STERLING JUNCTION
WORCESTER, NASHUA AND PORTLAND DIV. B. AND M. R.R.
NORTHERN DIV. O.C.R.R.
CENTRAL MASSACHUSETTS DIV. B. AND M. R.R.
Clarendon Mills
South Branch of
Nashua River
Sawyers Mills
BOYLSTON
Sawyers Mill Pond
Sandy Pond
Coachlace Pond
Bigelow Carpet Co.
CLINTON
Lancaster Mills
Lancaster Mill Pond
DIKE
DIKE
DIKE
DAM
BOYLSTON CENTER
W E S T B O Y L S T O N
S T E R L I N G
C L I N T O N
B O Y L S T O N
Outline of full reservoir (Elev. 385) thus:
" " reservoir when
lowered twenty-five feet (Elev. 360) thus:
Water area at Elev. 385 6.56 Sq. miles
" " " " 360 4.21 " "
Capacity " " 385 63,068,000,000 gallons
" " " 360 34,732,000,000 "
Figures give depths of water when reservoir is full.
0 500 1000 2000 3000 4000 5000
1 MILE

P128

Although the dam is smaller than several others which have been constructed, the capacity of the reservoir is greater than that of any existing reservoir of which I have information, and the average depth is unusually large. Comparison with other large reservoirs, as given in the following table, may be of interest. It has been compiled mainly from accurate information, but in a few instances approximate figures have been used: —

Comparative Table of Areas, Depths and Capacities of Storage Reservoirs, with Heights and Lengths of Dams.

Name and Location of Reservoir.	Area (Square Miles).	Average Depth (Feet).	Maximum Height of Dam. Above Ground.	Maximum Height of Dam. Above Rock.	Length of Dam (Feet).	Capacity (Million Gallons).
Swift River, Mass., . .	**36.96**	**53**	**144**	–	**2,470**	**406,000**
Nashua River, Mass., . .	**6.56**	**46**	**129**	**158**	**1,250**	**63,068**
Nira, near Poona, India, .	7.25	27	100	–	3,000	41,143
Tansa, Bombay, India, . .	5.50	33	127	131	8,770	37,500
Khadakvasla, Poona, India, .	5.50	32	100	107	5,080	36,737
San Mateo, Cal., . . .	–	–	170	–	–	32,000
New Croton, N. Y., . .	–	–	157	225	1,270	32,000
Elan and Claerwen, Birmingham, Eng., water works (total for six reservoirs), .	2.34	43	98 to 128	–	4,460	20,838
All Boston water works reservoirs combined, . .	5.82	14	14 to 65	–	–	15,867
Vyrnwy, Liverpool, Eng., .	1.75	–	84	129	1,350	14,560
Ware River, Mass., . .	**1.62**	**33**	**71**	–	**785**	**11,190**
Sodom, N. Y., ...	–	–	72	89	500	9,500
Hemet, San Jacinta, Cal., .	–	–	150	–	200	8,500
Reservoir No. 5, Boston water works, . . .	1.91	19	65	70	1,865	7,438
Titicus, N. Y., ...	–	–	105	115	–	7,000
Hobbs Brook, Cambridge water works, . . .	1.00	12	23	–	–	2,500
Cochituate, Boston water works, ...	1.35	8	–	–	–	2,160
Reservoir No. 6, Boston water works, . . .	0.29	25	52	–	1,500	1,500
Furens, France, . . .	–	–	146	184	–	422

NOTE. — The heights of dams are given from the ground and rock up to the level of full reservoir. The lengths of dams are the distances across the valleys at the level of full reservoir on the line of the main dam. The capacities are given in United States gallons.

General statistics relating to the Nashua Reservoir and the property to be taken in the different towns for its construction are given in the following table : —

Statistics relating to the Nashua River Reservoir.

Area of water surface (acres),	4,195
Area of water surface (square miles),	6.56
Total contents (gallons)	63,068,000,000
Length (miles),	8.41
Maximum width (miles),	2.05
Total length of shore line, not including islands (miles),	35.4
Maximum depth (feet),	129
Average depth (feet),	46
Mills within limits of reservoir : —	
Cotton mills,	4
Grist mill,	1
Saw-mill,	1
Total,	6
Length of railroad flooded (miles),	6.56
Length of roads flooded (miles) : —	
Clinton,	3.71
Boylston,	10.95
West Boylston,	4.20
Sterling,	0.35
Total,	19.21
Character of area to be flooded (acres) : —	
Cleared land,	2,000
Wooded land,	1,801
Stump land,	81
Water surfaces,	313
	4,195
Additional area required around margin of reservoir, including islands (acres),	968
Total area required for reservoir (acres),	5,163
Division of land required for reservoir, by towns (acres) : —	
Clinton,	1,125
Boylston,	2,761
West Boylston,	870
Sterling,	407
	5,163

Assessed value of real estate: —

Clinton: —

Total in town, 1894,	$5,246,500
Total in town, 1892,	4,892,070
Total required for reservoir, 1892,	45,600
Per cent. required for reservoir,	1

Boylston: —

Total in town, 1894,	$429,435
Total in town, 1893,	428,975
Total required for reservoir, 1893,	165,200
Per cent. required for reservoir,	39

West Boylston: —

Total in town, 1894,	$951,610
Total in town, 1893,	933,945
Total required for reservoir, 1893,	557,730
Per cent. required for reservoir,	60

Sterling: —

Total in town, 1894,	$749,770
Total in town, 1892,	751,450
Total required for reservoir, 1892,	10,340
Per cent. required for reservoir,	1

Inhabitants.

	Total in Town, by Census of 1890.	On Land required for Reservoir 1895.	
		Numbers.	Per Cent.
Clinton,	10,424	95	1
Boylston,	770	302	39
West Boylston,	3,019	1,305	43
Sterling,	1,244	9	1
Totals,	15,457	1,711	11

Dwellings.

	Total in Town by Assessor's Report, 1894.	On Land required for Reservoir.	
		Numbers.	Per Cent.
Clinton,	1,442	19	1
Boylston,	155	46	30
West Boylston,	480	157	33
Sterling,	545	2	.4
Totals,	2,622	224	9

Churches and School-houses within Limits of Reservoir.

	Churches.	School-houses.
Boylston,	1	2
West Boylston,	3	4
Totals,	4	6

Main Dam.

This dam is located across a narrow gorge about 3,000 feet above the dam of the Lancaster Mills at Clinton. At several points in this gorge the solid rock appears at the surface of the ground, and it is not far below it at any place; on this account, and because of the topography, it is proposed to build the dam entirely of masonry. Its general features are shown on Plan No. 8. The general form of the cross-section is the same as that adopted for the New Croton dam which is now being constructed by the city of New York, and is similar in many respects to other dams which have been constructed upon the Croton water works, to the Furens dam upon the Furens River in France, completed in 1866, and to the Tansa dam of the Bombay water works, completed in 1891.

The top of the dam is 10 feet above the level of the full reservoir. At the water level it has a thickness of 19 feet, and 145 feet below this level a thickness of 119½ feet. The total distance across the valley on the line of the main portion of the dam, at high-water level, is 1,250 feet; but only 750 feet of this length has a depth from high water to the rock exceeding 40 feet, and but 270 feet has a depth exceeding 120 feet. The maximum depth from high water to the rock at the down-stream edge of the dam is 158 feet.

Advantage has been taken of the favorable topography at the northerly end of the dam to provide a very long overfall and a waste channel for wasting the water during floods without permitting it to flow over or near the high part of the dam. The overfall has a length of 450 feet, and will discharge a quantity of water equal to 8 inches in depth over the whole water-shed in twenty-four hours, without raising the water in the reservoir to an excessive height. The greater part of the overfall is to have a masonry crest at the level of the full reservoir; but for a length of 120 feet it is proposed

to keep the masonry crest 3 feet lower, and to retain the water at the full height by means of stop planks or movable gates.

Gate-houses are provided on the up-stream and down-stream sides of the dam, with four 48-inch pipes connecting them, which are to serve the joint purpose of supplying water to the aqueduct leading to the Sudbury water-shed and of conveying the waste water to the river below. These pipes, with the large head upon them when the reservoir is nearly full, have sufficient capacity to take the waters of a large freshet.

In order to determine the best place in the gorge at which to locate the dam, many borings were made by driving into the ground 2½-inch pipes, and bringing the material inside of them to the surface by means of a strong stream of water forced down to the bottom through a 1-inch wash and drill pipe. Preliminary borings were made for a distance of about 600 feet along the gorge; and these, taken in connection with the topography of the ground and the points at which the rock appeared at the surface, showed conclusively that the dam should be located substantially as indicated upon the plan. After it was located borings were made to rock in and near the bottom of the gorge every 25 feet along the centre line of the dam, and generally at the corners of 50-foot squares on both sides of the centre from a line 100 feet above the dam to 200 feet below it. Up the slope from the bottom of the gorge, toward the south end of the dam, the borings were made about 100 feet apart on the line of the dam, and additional borings were made on each side — opposite those on the centre line. On the north slope of the gorge, test pits were dug to the rock at frequent intervals, the boring apparatus not being used. Very few boulders were encountered in making the borings or in digging the pits; and, as the results of the different borings corresponded well in regard to depth and the character of the rock upon which they stopped, it seems probable that the ledge was reached in nearly every case. As, however, the upper portion of the ledge is likely to be broken and seamy, it is estimated that the masonry will extend to an average depth of 10 feet below the surface of the ledge as determined by the borings, and further provision has been made for preventing the filtration of water by cutting two trenches 8 feet wide into the ledge to a further depth of 8 feet, and filling them with masonry.

In order to ascertain the total cost of the dam, designs have been made for the temporary dams and flume which will be required to protect the deep excavation for the main dam from water. The bottom of the valley where the dam is to be built is at present occupied by the millpond of the Lancaster Mills. It will be necessary to drain this pond during the construction of the dam, and in order to prevent the water from backing up during heavy floods and filling the deep excavation, it will be necessary to take down a portion of the Lancaster Mills dam, which can be rebuilt after the work upon the main dam has been raised above the water level. The cost of this work, including an allowance to the Lancaster Mills for damages due to interference with its dam, is included in the estimate of the cost of the main dam, which amounts to $1,723,010.

Plan No. 9 shows comparative sections of several masonry dams and of the valleys where they are located.

The New Croton dam, which is now being constructed, is very much more extensive both in height and in the length of the high portion than the proposed Nashua dam.

The Furens dam is somewhat higher and has less length, and the Tansa dam somewhat lower and has much greater length, than the Nashua.

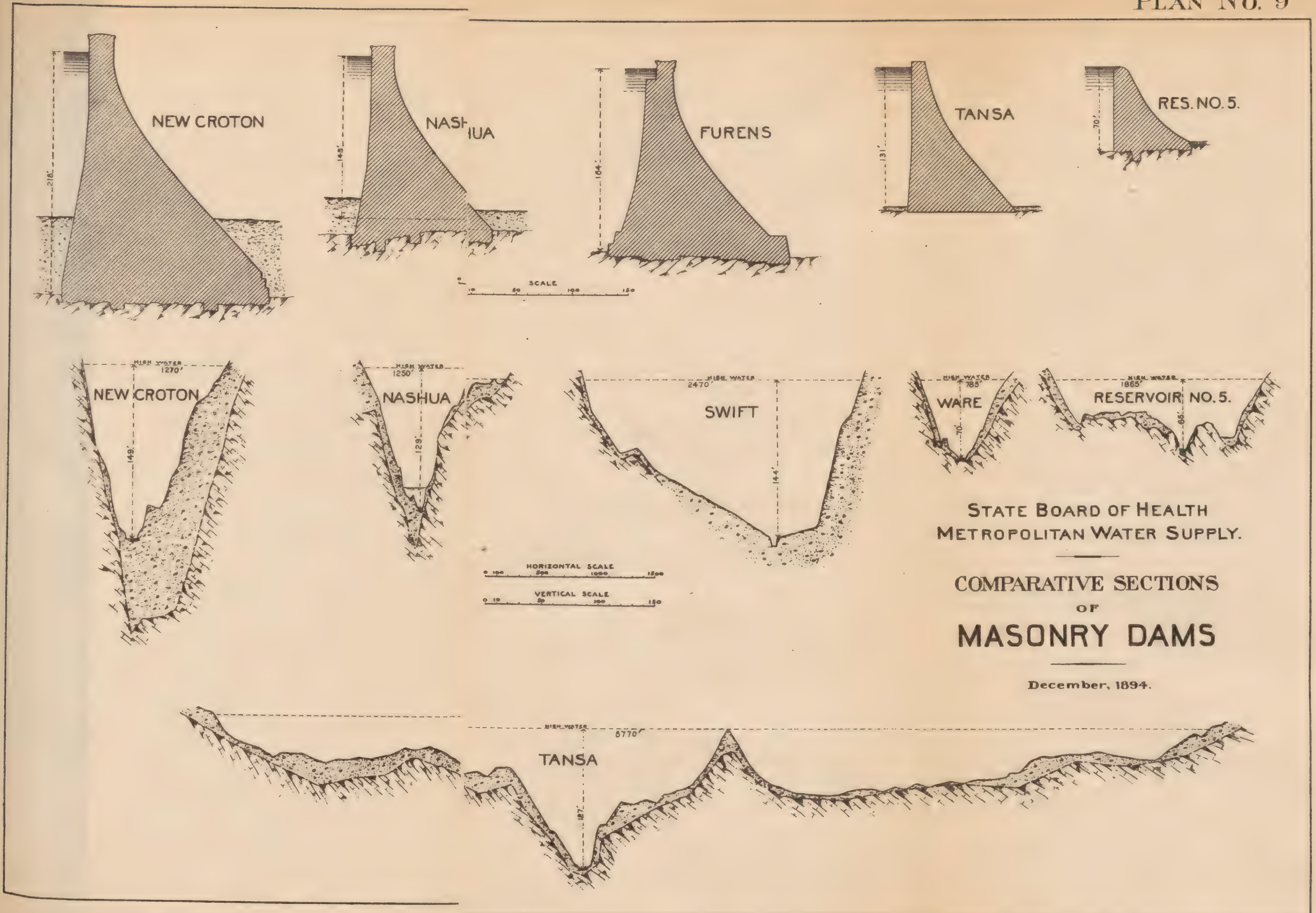
The greater part of the dam of Reservoir No. 5 is being built of earth with a masonry core wall, and as the section of masonry shown upon the plan is to be used only where the water is to overflow, it is designed of a different form from the other masonry dams shown.

The Tansa dam is thin at the top, but it is situated in a warm climate, where it does not have to resist the expansive force of ice.

Dikes.

On the north side of the lower portion of the reservoir there is the extensive sandy plain already referred to, which has a general level about 15 feet lower than the high-water level of the reservoir, and the water would flow out over it if not prevented by a dike. The plain contains some valleys and many bowl-shaped depressions, of which Sandy Pond is the largest.

After extended surveys and many borings, it was concluded to locate the northerly dike as shown upon Plan No. 7, and to construct it mainly of the soil taken from the reservoir, using the cross-section shown upon Plan No. 8.



STATE BOARD OF HEALTH
METROPOLITAN WATER SUPPLY.

COMPARATIVE SECTIONS
OF
MASONRY DAMS

December, 1894.

HELIOTYPE PRINTING CO., BOSTON.

The borings, which ranged in depth from 16 to 175 feet below the surface of the ground, showed that the portion of the plain where the dike was finally located is composed mainly of very fine sand which is nearly impervious to water; but, as already indicated by the great depth which the borings reached, the rock is so far below the surface that it would be impracticable to extend any cut-off wall down to it.

The impervious character of the material is well illustrated by the results found while making the boring 175 feet deep. This boring was made at a point where the surface of the ground was 15 feet above the ground-water level. The $2\frac{1}{2}$-inch casing pipe was driven to a depth of 23 feet; and the 1-inch wash pipe, with a stream of water from a hydrant flowing through it, was forced down 152 feet farther. Notwithstanding the opportunity thus afforded for the water from the 1 inch pipe to percolate into the ground, it did not do so, but came up to the surface in a strong stream. Many of the other borings showed similar results.

In view of these conditions, and the fact that a dumping place was needed for the vast amount of soil to be removed from the site of the reservoir in order to improve the quality of the water, it was decided to make this dike of very great width, as indicated by the sections, and thereby insure safety and a minimum amount of percolation from the reservoir.

The top of the dike is raised 15 feet above the high-water level in the reservoir, and is made 50 feet wide, The slopes are four horizontal to one vertical on either side, so that the distance through the embankment at the water level is 170 feet. From this point the down-stream side of the embankment is to have a slope of only 3 feet in 100. The reservoir slope of the embankment is to be formed of a thick bed of gravel, covered with broken stone and paving or rip-rap. Where the dike crosses the outlet of Sandy Pond it attains a maximum height of about 68 feet up to the level of the water in the reservoir, and at this place it has a width, measured along the line of the outlet, of more than two-fifths of a mile.

The dike is divided into two portions by a rocky hill which rises above the level of the plain. The length of the easterly portion, measured at the level of high water, is 3,815 feet, and of the westerly portion 4,735 feet, making the total length 8,550 feet. The estimated cost of the easterly portion is $321,370 and of the westerly portion $130,570, making the total estimated cost $451,940.

About two-thirds of a mile south of the main dam there is another low place, where a dike is required to prevent the water of the reservoir from overflowing. The conditions at this place are different from those at the location of the north dike, as the ground is generally higher, and rock is found close to the surface of the ground most of the way and only about 24 feet below the surface in the deepest place. This dike is therefore designed, as shown on Plan No. 8, to consist of an earth embankment, with a concrete core wall extending to the solid rock. The top of the dike is 50 feet wide and 10 feet above the level of the water in the reservoir. The slopes are two horizontal to one vertical, and the one toward the reservoir is to be protected with heavy paving resting upon broken stone. The length of this dike at the level of the water line is 2,500 feet, and its estimated cost is $206,110.

Removal of Soil from Reservoir.

Experience has shown that the waters of many storage reservoirs which have been flowed without removing the soil and vegetable matter from them frequently contain abundant growths of the minute organisms which give water a disagreeable taste and odor, and more organic matter than is desirable in a drinking water.

In some cases, and more particularly in those where swampy land has been flooded, the unfavorable effect of flooding the reservoir without cleaning it has continued for twenty years or more without any apparent diminution. In some other cases the bad effect of such flooding, while very marked at first, has diminished, and this might be the case with the reservoir under consideration.

In the case of thoroughly prepared reservoirs which are supplied with unpolluted water, the experience has been very favorable. Reservoir No. 4 of the Boston water works was prepared in this way, and from the time it was first filled, in 1886, its water has always been comparatively free from the organisms referred to. It has also stood certain tests relative to the accumulation of the products of decomposition in its lower layers during the period of stagnation in summer much better than any of several natural ponds tested in a similar manner, with the exception of Lake Winnipiseogee.

In view of the certainty that the water of the Nashua reservoir would contain less organic matter and be much less liable to be affected by disagreeable tastes and odors if the soil were removed, it was concluded to make provision for removing the whole of it.

The estimated cost of this work is $2,909,600, which is a very large sum, but not large in proportion to the great capacity of the reservoir. By estimates made in the same manner as those given on page 85, I find that the interest and payments to the sinking fund which would extinguish in forty years the debt due to the removal of the soil would amount to only eleven cents per year per inhabitant.

In order to determine the amount of soil to be removed, a number of test pits were dug in representative locations to a depth of 3 feet, and from the sides of these pits samples of the soil were carefully collected at different depths. Near the surface the samples were taken two or three inches apart, and further down at somewhat greater intervals. These samples were analyzed, with the results given in Appendix No. 4. The analyses demonstrated that the amount of organic matter in the ground was generally so small below the layer of black loam that it would be necessary to remove only this layer. In order to determine the average depth of this layer, 814 holes were dug in different portions of the reservoir, and it was found that in the wooded land the average depth was 6.95 inches and in the cleared land 10.18 inches. This difference is occasioned largely by the fact that the slopes are generally wooded and the bottom lands are cleared. As it would not be feasible to remove all of the black loam without taking some of the material beneath it, it was assumed that an average of 9 inches would be removed from the wooded land and 11½ inches from the cleared land.

There are areas near the edges of the reservoir from which the soil could be removed to a suitable point outside of it by teams, scrapers or other well-known means for conveying earth a short distance; but by far the greater part would have to be carried so far and raised to so great a height to take it to a suitable place of deposit that the use of a railroad and trains would be necessary. A favorable opportunity for running trains out of the reservoir and for dumping the soil is furnished at the location of the north dike. As the soil would be utilized in the dikes and would be placed where it could not unfavorably affect the quality of the water in the reservoir, it is proposed to dispose of most of it in this way.

In estimating the cost of this work, a study was made to determine the locations where the soil from each portion of the reservoir could be placed; and where it is to be removed by trains the cost of all of the various operations required to take the soil from its original position and finally dispose of it is included in the estimates.

Relocation of Railroads and Highways.

As already stated in the statistical table, the proposed reservoir will flood the present location of the Central Massachusetts Railroad for a distance of 6.56 miles and to a maximum depth of 94 feet. As it would be impracticable to raise the road in its present location, surveys have been made for its relocation.

Four routes have been surveyed; two of them provide for carrying the railroad near the southerly margin of the reservoir from the south dike to Boylston, and crossing the reservoir at this place by means of a bridge resting upon stone piers having a maximum height of 110 feet. After crossing the reservoir one route follows along its northerly side to Oakdale, and the other runs about a mile and a half to the Worcester, Nashua & Rochester Railroad, which, like the Central Massachusetts, is operated by the Boston & Maine Railroad Company; thence to follow the Worcester, Nashua & Rochester Railroad to Oakdale. The bridge at Boylston would be 1,800 feet long and it would be costly on account of the great depth of the water and the necessity for making the stone piers extremely heavy to enable them to withstand the expansive force of the ice.

The other two routes provide for leaving the present location of the Central Massachusetts Railroad at West Berlin, crossing the river below the main dam and joining the Worcester, Nashua & Rochester Railroad in Clinton. The bridge over the river for these routes would be high; but as the piers would not be in deep water, iron trestles could be used instead of stone piers, materially reducing the cost.

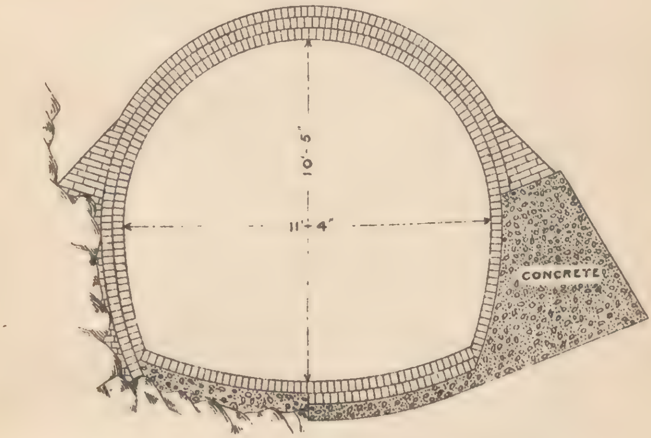
If a railroad bridge were to be built across the reservoir at Boylston, it could be made to carry also a highway across the reservoir at this place. If it should be considered necessary to provide for a highway crossing at Boylston in any case, the railroad could be constructed more cheaply upon the route crossing the reservoir at this place and running to the Worcester, Nashua & Rochester Railroad than by any other route; but if a highway bridge were not considered necessary, there would be little difference in the cost of the railroad on the route just mentioned and on those nearer Clinton.

The Worcester, Nashua & Rochester Railroad passes through the upper end of the reservoir at Oakdale, but the tracks are slightly above the high-water level of the reservoir. It would be necessary

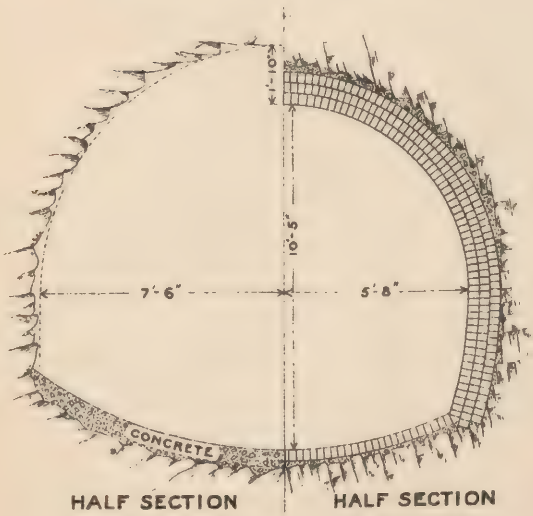
STATE BOARD OF HEALTH
METROPOLITAN WATER SUPPLY.

CROSS SECTIONS
OF THE PROPOSED
NASHUA-SUDBURY AQUEDUCT

December, 1894.



HALF SECTION IN ROCK. HALF SECTION IN EARTH.



HALF SECTION UNLINED TUNNEL. HALF SECTION LINED TUNNEL.

0 1 2 3 4 5 10
Scale of feet

HELIOTYPE PRINTING Co., BOSTON.

however, to raise the tracks further above the water and to protect the embankment from washing. The various roads and highways in the reservoir would be flooded to such a depth that they could not be raised; and it is therefore proposed to construct marginal roads around the reservoir and bridges across it at West Boylston and Oakdale.

Nashua–Sudbury Aqueduct.

This aqueduct starts from a gate chamber on the lower side of the proposed Nashua River dam, as shown upon Plan No. 8, and runs 8.87 miles to a point in the Sudbury water-shed just beyond the New York, New Haven & Hartford Railroad. The route of the aqueduct is shown on Plan No. 2 and in more detail on Plans Nos. 4 and 5; and a profile on a small scale is shown on Plan No. 2.

The aqueduct is to have the cross-section indicated upon Plan No. 10, and to be as a rule 11 feet 4 inches wide and 10 feet 5 inches high; but is to be made larger in the portions of the tunnel which do not require lining with brickwork. The aqueduct has an inclination of 1 in 2,500, and a maximum capacity of 300,000,000 gallons per day.

For 1.94 miles from the dam, to a point near the New York, New Haven & Hartford Railroad, one-fourth of a mile south of the village of West Berlin, the aqueduct will be in tunnel. From the end of the tunnel to the lower end of the aqueduct an easy line can be obtained everywhere except at and near the crossing of the Assabet River, where some heavy cutting on either side of the river, and a bridge, consisting of masonry arches, will be required.

From the lower end of the aqueduct to Reservoir No. 5 it is proposed to excavate a channel in the bottom of the valley having a depth of about 10 feet, a bottom width of 20 feet and side slopes of four horizontal to one vertical. This channel, which has a total length of 3.03 miles, would have a grade of 1 in 2,500, and would be provided with dams across it at two points, having adjustable openings by which the velocity could be regulated so as to prevent the scouring of the bottom of the channel. These dams could also be used to maintain a sufficient depth of water in the channel, so that there would be a sufficient passage for the water beneath the ice that might form in winter.

The portions of the work which would require the longest time for their completion are the tunnel and the bridge over the Assabet River; but it is making a liberal allowance for delays to estimate

that, if the metropolitan water supply should be authorized by the Legislature of 1895, the aqueduct would be ready for use in 1898.

The estimated cost of the aqueduct and open channel, including land damages, is $2,265,000.

Improvement of the Sudbury River Water-shed.

Appendix No. 3 is a report by Mr. Desmond FitzGerald upon improving the quality of the Sudbury River water by the drainage of the swamps upon the water-shed, and he there estimates the total cost of carrying out all the drainage schemes to be $350,000.

By far the greater proportion of the swampy land is within the water-shed drained by the main Sudbury River, and not upon the Stony Brook branch, through which the waters of the Nashua River will pass. As the Nashua River and the Stony Brook branch of the Sudbury River water-shed will furnish all of the water required for many years after the works are first built, I have not included in the present estimates the improvement of any portion of the Sudbury water-shed other than that which drains into Stony Brook.

Upon this portion there is one large swamp at the head of the valley into which the Nashua-Sudbury aqueduct will flow, and it is proposed to drain this swamp and others upon the Stony Brook water-shed; and for this purpose and for other sanitary improvements upon this water-shed $63,000 have been included in the estimates.

Reservoir No. 5 to Chestnut Hill Reservoir.

When the water is turned into the upper end of Reservoir No. 5 it will flow through existing channels to Chestnut Hill Reservoir; but on account of the increased quantity of water it will be necessary to provide larger culverts than would otherwise be necessary through the roads and railroads crossing the portion of Reservoir No. 5 through which this water is to flow, and larger openings through Dam No. 5. In order to prevent this water from mingling with the water of the main Sudbury River, a second 48-inch pipe will be required from Dam No. 3 to the head of the Sudbury aqueduct at Dam No. 1, a third 48-inch pipe will also be required across the Rosemary valley.

The city of Boston, having in view the future supply from the Nashua River, has provided openings through Dam No. 5 of sufficient size to take all of the water which will come from this source.

When the first reservoirs were built upon the Sudbury works, a 48-inch pipe was laid from Dam No. 3 to Dam No. 1, but no provision was made for a second one. It is feasible, however, by cutting through the masonry of the gate houses, by enlarging certain gates and by drawing down Reservoir No. 1, which is little used, to lay the second pipe without any great difficulty. At the crossing of the Rosemary valley provision was made in the original plan for a third pipe, and portions of the pipe already extend beyond the walls of the siphon chambers. No difficulty will therefore be encountered in laying the third pipe.

The total cost of these pipes and of the enlargement of gates and other incidental work is estimated to be $78,800.

Pumping Stations.

High-service Pumping Station at Chestnut Hill Reservoir. — It is proposed, as has already been stated, to utilize the present high-service pumping station of the city of Boston for pumping water for the southern high service. This pumping station contains two 8,000,000 gallon pumps, which were put in when the station was built, and one 20,000,000 gallon high-duty pump, which has been in use but a short time. The building was originally designed with a view to its extension, and by building this extension and adding another 20,000,000 gallon pump the capacity will be increased so as to meet all requirements for a long time in the future. The estimated cost of the extension of the building and the additional pump is $211,750.

Low-service and Extra High-service Pumping Station at Chestnut Hill Reservoir. — It is proposed to combine both of these services in one new building. Provision has been made for three high-duty low-service pumps, each capable of lifting 40,000,000 gallons of water per day with great economy to a height of 40 feet, and with less economy to a height of 60 feet, if so great a lift should at any time be necessary.

The extra high-service pumps will be very small in comparison with the others, as they would only need to have a capacity of 2,000,000 gallons per day. There would be two of these pumps, one to be kept in reserve while the other is in use.

In order to supply these pumps with water it is proposed to make much larger connections with Chestnut Hill Reservoir, and to lay

an additional 48-inch pipe from the terminal chamber of the Sudbury aqueduct to the pumping station.

The estimated cost of this pumping station with pumps and boilers complete and the enlarged connections above referred to, including all incidental expenses, is estimated to be $781,214.

Northern High-service Pumping Station. — This pumping station is to be located in Malden, at some place where coal can be readily obtained and where salt water will be available for condensing purposes. It is proposed to provide three high-duty pumping engines, each capable of lifting 15,000,000 gallons daily against the pressure due to a head of 140 feet. The cost of this pumping station and all appurtenances, including the cost of land, is estimated to be $560,000.

Northern Extra High-service Pumping Station. — This station is to be located in the town of Arlington, and is intended to supply Arlington Heights and Lexington, and in the future small portions of Belmont and Waltham. This station is very small in comparison with the others and is estimated to cost $25,875.

Receiving and Distributing Reservoirs.

Chestnut Hill Reservoir, which has an area of 125 acres and contains 557,000,000 gallons in the first 25 feet in depth, forms an ample receiving basin and will require no changes, except slight ones, where the enlarged connections with the pumping station before referred to will be made.

Spot Pond, which has an area of 296 acres and contains 733,000,000 gallons in the first 12 feet and 837,000,000 gallons in the first 15 feet below high-water level, will serve as an equalizing and distributing reservoir for the low service, and with Chestnut Hill Reservoir will provide a very large and important reserve of water within the metropolitan district, if in any event the supply from the more distant sources should be temporarily interrupted.

The proposed improvement of Spot Pond, for which $181,840 has been included in the estimates, provides for removing the mud from shallow portions to a depth of 12 feet below high-water mark, and for using the material excavated to fill other portions. It also provides for covering the exposed slopes of the filled portions with a thick layer of gravel.

The proposed distributing reservoir for the northern high service, located in the Middlesex Fells, is to have its water surface 270 feet

above Boston water works base, and to contain 13,100,000 gallons. Owing to the abundance of rock at the site of this reservoir, it is proposed to retain the water in it by means of walls of stone masonry laid in cement. The estimated cost of the reservoir is $125,140; and for an additional $118,000 the reservoir can be enlarged whenever it becomes necessary so as to have a capacity of 32,000,000 gallons.

The only other reservoir to be built in connection with the metropolitan supply is the iron tank, already referred to, in the city of Quincy, which will have a capacity of 2,000,000 gallons, and, with such architectural additions as may be necessary to prevent it from being unsightly, is estimated to cost $80,320.

In addition to these reservoirs there are 37 other reservoirs and tanks now owned by the different cities and towns, most of which it is proposed to utilize to a greater or less extent, either to provide a reserve for the individual cities and towns, or for larger portions of the district.

Pipe Systems.

Plan No. 6 and the descriptions already given indicate so fully the general method of distributing the water throughout the district that no additional description is necessary.

The estimates have been based wholly upon the use of cast-iron pipe, and the largest pipe used is 48 inches in diameter.

The routes have been selected with reference to directness, to utilizing streets which are not now too much occupied with pipes, and to encountering a minimum amount of rock. All of the proposed pipe lines have been examined in detail, and the amount of rock to be encountered has been determined as well as practicable from information obtained by inspection upon the ground and from local authorities who had laid water pipes and sewers in the streets where the pipe lines are located.

The pipes are of larger sizes than have usually been adopted, but careful estimates have shown that this is a measure of ultimate economy, as well as a present advantage in supplying an abundance of water for all emergencies; moreover, with the increasing number of pipes and conduits to be laid in the streets for different purposes, it is desirable not to increase the number unnecessarily, and it is obviously desirable to avoid the frequent digging up of the streets.

The following table gives the length of each size of pipe and the amount included in each service: —

Length in Miles of Pipe required for distributing Water to the Cities and Towns in the Metropolitan Water District.

DIAMETER OF PIPE (INCHES).	Low Service.	Northern High Service.	Northern Extra High Service.	Southern High Service.	Southern Extra High Service.	Total.
48, ...	26.60	–	–	4.00	–	30.60
42, ...	1.53	.64	–		–	2.17
36, ...	.08	6.25	–	5.72	–	12.05
30, ...	–	2.73	–	–	–	2.73
24, ...	–	1.18	–	7.35	–	8.53
20, ...	.70	3.41	–	1.89	3.61	9.61
18, ...	–	4.88	–	.82	–	5.70
16, ...	1.75	1.82	1.14	–	4.21	8.92
14, ...	–	1.75	–	–	–	1.75
12, ...	–	3.45	2.53	–	6.85	12.83
6 (blow-off pipe), . .	.17	.07	.01	.03	.05	.33
Total, ...	30.83	26.18	3.68	19.81	14.72	95.22

The total estimated cost of the piping is $3,617,861.

Future Aqueduct from Reservoir No. 5, to the Metropolitan District.

The route of this aqueduct, including the proposed future pipe lines from its terminus in Weston to Chestnut Hill Reservoir and to a connection with pipes previously laid at Arlington, is shown on Plan No. 2; and a profile of the aqueduct is also shown upon this plan.

The route is a very favorable one, as the cuttings are comparatively light, and support can be obtained for an aqueduct for the whole length with the exception of 4,100 feet at the crossing of Sudbury River, where pipes will have to be used; there is only one tunnel on the line, and that only 700 feet long.

From the beginning of the aqueduct at Reservoir No. 5 to the siphon, a distance of 5.61 miles, the aqueduct is to have an inclination of 1 in 2,500, and is to be 10 feet 6 inches wide and 9 feet 8 inches high. From the siphon to the terminus of the aqueduct in Weston, a distance of 6.88 miles, it is to have a grade of 1 in 5,000 and to be 12 feet wide and 11 feet high. The capacity of this aque-

duct when running full will be 250,000,000 gallons per day. Its route is, as a rule, away from centres of population, and the land damages will therefore be small. The estimated cost of the aqueduct, including land damages, at present prices, is $3,226,000.

The pipe lines from the terminus of the aqueduct to Chestnut Hill Reservoir and to Arlington have not been as carefully located as the aqueduct, because it was obvious that, as they are not to be built for about ten years, a location could be selected better in the future than at the present time, as there would be many new streets in which the pipes might be laid, thereby avoiding the damages occasioned by passing through private land. It was found, as has already been stated, that for 1.94 miles west of Chestnut Hill Reservoir the ground was high enough so that an aqueduct might be used instead of the pipes; and the estimates for the line to this reservoir include an aqueduct 10 feet 6 inches wide, 9 feet 8 inches high, and of sufficient capacity to carry as much water as four 48-inch pipes would bring to it.

The future pipe lines from the aqueduct at Weston would not necessarily all run either to Chestnut Hill, or Arlington and Medford, but some of them might run to the main pipe lines at intermediate points.

Estimates of Cost.

The following tables contain estimates of the cost of the proposed works in greater detail than they have been given on page 79: —

Improving Nashua River Water-shed.

Main sewers for villages and mills in the Quinepoxet valley, including the cost of making connections with the mills,	$152,000	
Pumping station and force mains,	36,000	
Filter beds,	19,000	
Draining swamps,	143,000	
Cleaning out or draining mill ponds, and miscellaneous items of work incidental to the sanitary protection of the water-shed,	100,000	
		$450,000

Storage Reservoir.

Main dam,	$1,723,010	
North dike, easterly portion,	321,370	
North dike, westerly portion,	130,570	
South dike,	206,110	
Amounts carried forward,	$2,381,060	$450,000

Amounts brought forward, ...	$2,381,060	$450,000
Removal of soil from reservoir, ...	2,909,600	
Relocation and raising of roads and railroads, including bridges across the reservoir at Boylston, West Boylston and Oakdale, ...	1,516,500	
Land, buildings and water rights to be taken, including taxes during construction, ...	2,297,840	
		9,105,000

Nashua–Sudbury Aqueduct.

8.87 miles aqueduct, including tunnel, bridge over Assabet River, land damages and all appurtenances except gate house at upper end, which is included in the cost of the dam, ...	$2,101,000	
3.03 miles open channel from terminus of aqueduct to Reservoir No. 5, including land damages, and appurtenances, ...	164,000	
		2,265,000

Improving Stony Brook Branch of Sudbury Water-shed.

Draining swamps and miscellaneous items of work incidental to the sanitary protection of this water-shed, .		63,000

Additions to Existing Works, Reservoir No. 5 to Chestnut Hill.

One 48-inch pipe 5,185 feet long, from Dam No. 3 to Dam No. 1, including connections with gate houses and enlargement of gates, ...	$57,300	
One 48-inch pipe 1,800 feet long across Rosemary valley, with blow-off, ...	21,500	
		78,800

High-service Pumping Station at Chestnut Hill Reservoir.

Addition to present building, ...	$49,500	
Additional 20,000,000 gallon high-duty pumping engine and all appurtenances, ...	162,250	
		211,750

Low-service and Extra High-service Pumping Station at Chestnut Hill Reservoir.

Connections with Chestnut Hill Reservoir, including land damages, ...	$84,700	
One 48-inch pipe from terminal chamber of Sudbury aqueduct to pumping station, ...	22,700	
Pumping station building and foundations, . . .	165,400	
Three 40,000,000 gallon and two 2,000,000 gallon pumps, with foundations, boilers, connections and all appurtenances complete, ...	508,414	
		781,214
Amount carried forward, ...		$12,954,764

Amount brought forward,		$12,954,764
Northern High-service Pumping Station at Malden.		
Three 15,000,000 high-duty pumping engines, including all appurtenances, buildings and cost of land,		560,000
Northern Extra High-service Pumping Station at Arlington.		
Pumping station complete, including cost of land,		25,875
Distributing Reservoirs.		
Improvement of Spot Pond,	$181,840	
Northern high-service distributing reservoir in Middlesex Fells,	125,140	
Iron tank on Forbes Hill, Quincy,	80,320	
		387,300
Pipe Systems.		
Low service,	$1,981,700	
Southern high service,	724,000	
Northern high service,	675,900	
Southern extra high service,	194,000	
Northern extra high service,	42,261	
		3,617,861
Damages for Diversion of Water from the Nashua River and Incidental Damages not included above.		
Total estimated amount,		1,500,000
Total first cost of proposed works for supplying water to *all* of the cities and towns in the metropolitan district,		$19,045,800

SUMMARY.

The urgent need of an additional water supply for the metropolitan district is shown by the following figures: —

	Gallons.
Average daily consumption of water in 1890,	57,818,000
Average daily consumption of water in 1894,	79,046,000
Estimated daily consumption of water in 1898,	100,026,000
Average daily capacity of present sources in a very dry year,	83,700,000

The additional water supply required cannot be obtained by developing the present sources.

There are many cities and towns in the metropolitan district which are in more urgent need of an additional water supply than the district as a whole, a few which have a sufficient supply for the near future, and a very few which might obtain by themselves a supply for the next fifteen or twenty-five years.

Classifying the cities and towns by the date at which they will reach the capacity of their present sources of supply when fully developed, I obtain the following results : —

	Population in 1895.	Per Cent.
On or before 1900,	834,238	84.4
1901–1910,	35,400	3.6
1911–1920,	118,255	12.0
Total,	987,893	100.0

Investigations and estimates show that an additional water supply can be furnished by combined action at much less cost than by independent action, particularly if existing works are utilized to avoid duplication.

The South Branch of the Nashua River is by far the best source from which to take an additional water supply, because it will furnish by gravity, with the least delay and at the least cost, a very large quantity of pure water; and it is capable of being supplemented, from time to time, from other sources, which will furnish a practically unlimited supply of still purer water at a comparatively small cost.

Respectfully submitted,

FREDERIC P. STEARNS,

Chief Engineer.

BOSTON, MASS., Feb. 5, 1895.

APPENDICES

TO

REPORT OF CHIEF ENGINEER.

Appendix No. 1.

GROWTH OF POPULATION IN THE BOSTON METROPOLITAN DISTRICT.

In determining the future needs of the metropolitan district with regard to the amount of water to be supplied, it is obvious that much depends upon the future growth of population in the district. It is also obvious that no estimate of future population can be other than a rough approximation, because the future growth of the district depends upon so many factors which are at present unknown.

In estimating the future growth of any given community, we have to depend mainly on the indications furnished by the past growth of the community; but the recorded growth of other communities, after reaching the size of the community under consideration, also affords valuable information. It is always best, in estimating the growth of large centres of population, to ignore the arbitrary limits of city and town boundaries, and to use a limit which will include all of the inhabitants that properly form a part of the centre under consideration. In the case of Boston the ten-mile limit seems to be a satisfactory one. Within this limit the growth as indicated by the censuses from 1850 to 1890 has been as follows: —

YEAR.	Population.	Increase per Year.	YEAR.	Population.	Increase per Year.
1850, . . .	269,754	–	1875, . .	583,050	18,450
1855, . . .	328,412	11,732	1880, . .	631,944	9,779
1860, . . .	384,672	11,252	1885, . .	708,239	15,259
1865, . . .	416,763	6,418	1890, . .	844,814	27,315
1870, . . .	490,798	14,807			

By using the partial censuses of population, such as the assessed polls, the names in the directory and the enumeration of school children, and by making a comparison of other statistics which indicate to some extent the growth of communities, such as the number of buildings erected and the number of water services added, it has been feasible to obtain the population of the district for the years 1891 to 1894 with much greater accuracy than they could be obtained by a prediction based upon the previous rate of growth alone. The results obtained in this way are as follows: —

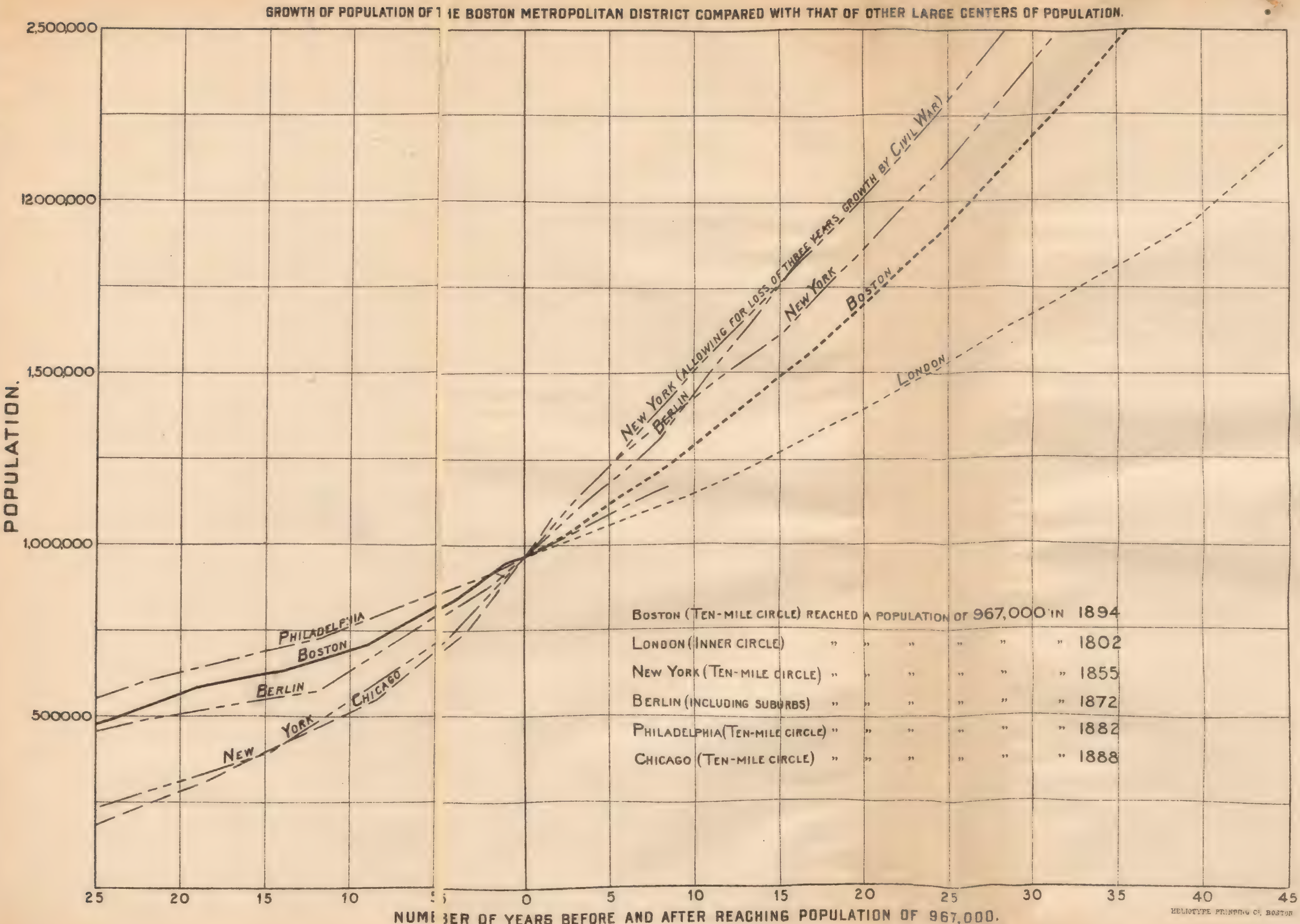
YEAR.	Population.	Increase per Year.	YEAR.	Population.	Increase per Year.
1890, . . .	844,814	–	1893, . .	953,625	32,671
1891, . . .	884,094	39,280	1894, . .	966,842	13,217
1892, . . .	920,954	36,860			

In addition to the basis for estimates furnished by the past growth of the community under consideration, and of other larger communities, we may use our judgment as to whether the causes which have induced growth in the past are likely to operate more or less effectively in the future. In the case of Boston I have not found any reason to modify the estimate of future population based upon its past growth and the growth of other cities. There has been a tendency to predict a slower growth for Boston in the future, because of its remoteness from the sources of raw materials and the principal markets of the United States. In opposition to this prediction we have the fact that the growth of the district has been very much more rapid during the past nine years than in any previous nine years; and it can hardly be said that the conditions are any less favorable for rapid future growth at the present time than they were nine years ago.

The estimated future population of the Boston metropolitan district upon the basis already indicated is as follows: —

YEAR.	Population.	Increase per Year.	YEAR.	Population.	Increase per Year.
1895, . . .	984,301	–	1915, . .	1,743,510	43,377
1900, . . .	1,148,033	32,746	1920, . .	1,979,930	47,284
1905, . . .	1,328,787	36,151	1925, . .	2,238,500	51,714
1910, . . .	1,526,623	39,567	1930, . .	2,521,875	56,675

PLAN NO. 11



HELIOTYPE PRINTING CO. BOSTON

Both the past and estimated future growth of the Boston metropolitan district are shown graphically upon an accompanying diagram, in comparison with the growth of New York, Philadelphia, Chicago, London, and Berlin. The lines representing the population of each of these places are so placed upon the diagram as to coincide at the point where the population is 967,000, — the estimated population of the Boston metropolitan district in 1894. The populations of New York, Philadelphia, and Chicago are the populations within a radius of ten miles from the business centre.

New York reached the population of 967,000 in 1855, and its growth since that time has been much more rapid than the estimated future growth of the Boston metropolitan district, notwithstanding the occurrence of the civil war, which materially retarded the growth of New York between the censuses of 1860 and 1870.

In 1890, when the last official census was taken, the populations of Philadelphia and Chicago were not enough in excess of the population of the Boston district in 1894 to furnish a satisfactory guide to the future growth of this district. It may be said, however, that Philadelphia continued to grow after reaching this population at the same rate as before, and more slowly than Boston, while Chicago is shown both by the returns and by more recent information of a less accurate character to be growing very much more rapidly than Boston.

Of the foreign cities, London reached the population of 967,000 at the beginning of this century, when the conditions with regard to transportation and many other things were so different from those existing at the present time that the growth of this city does not furnish a satisfactory guide for estimating the future growth of modern cities. "Greater London," however, furnishes an interesting example of how rapidly a city may grow after it has reached an immense size, since it has for the last fifty years maintained a nearly constant rate of increase of twenty per cent. every ten years, as will be seen by the following table, taken from the "Report of the Royal Commission appointed to inquire into the Water Supply of the Metropolis:" —

Population of "Greater London."

CENSUS OF	Population.	Increase per Cent. in the Previous Decennium.	CENSUS OF	Population.	Increase per Cent. in the Previous Decennium.
1841, . . .	2,235,344	–	1871, . .	3,885,641	20.6
1851, . . .	2,680,735	19.9	1881, . .	4,766,661	22.7
1861, . . .	3,222,720	20.2	1891, . .	5,633,332	18.2

Berlin with its suburbs reached a population of 967,000 in 1872, and its growth since that time has been even more rapid than that of New York.

The growth of Paris has not been placed upon the diagram, mainly because censuses of population prior to 1861 of certain territory annexed to the city between 1856 and 1861 are not available, and also because the growth of the city was practically stopped for two five-year periods, which included, respectively, the Revolution of 1848 and the Franco-German war. The statistics which are available are as follows: —

Population of the City of Paris since 1800.

YEAR.	Population.	YEAR.	Population.
1800, ...	547,756	1856, ...	1,174,346
1811, ...	622,636	1861, ...	1,696,741
1817, ...	713,966	1866, ...	1,825,792
1831, ...	785,862	1872, ...	1,851,792
1836, ...	868,438	1876, ...	1,988,806
1841, ...	935,261	1881, ...	2,269,023
1846, ...	1,053,897	1886, ...	2,344,550
1851, ...	1,053,262	1891, ...	2,447,957

After estimating the future population of the whole district within the ten-mile limit, the several municipalities were taken separately, and the results obtained in this way were so adjusted as to make the total population agree with that already obtained for the whole district. The results of these estimates of future population of each of the cities and towns, together with the past population for each half decade since 1850, are given in the large folded table.

The Charles River divides the metropolitan district into two nearly equal parts, that upon the north side of the river containing at the present time a somewhat smaller population than that upon the south side; but, owing to the more rapid growth of the north side, it is estimated that its population will equal that of the south side in 1902 and exceed it by about one-fifth in 1930.

Tables which follow contain statistics of the growth of population of Boston, New York, Philadelphia and Chicago, within a radius of ten and fifteen miles from the centre of population, and the population of London and Berlin with and without suburbs: —

Table showing Growth of Population of the Boston Metropolitan District.

The populations from 1850 to 1890 are from the Census reports; those from 1895 to 1930 are estimated.

	City or Town.	1850.	Increase. In Numbers.	Increase. Per Cent.	1855.	Increase. In Numbers.	Increase. Per Cent.	1860.	Increase. In Numbers.	Increase. Per Cent.	1865.	Increase. In Numbers.	Increase. Per Cent.
1	Boston (city proper),	113,721	12,575	11.1	126,296	7,267	5.8	133,563	7,520	5.6	141,083	*2,302	*1.6
2	East Boston,	9,861	6,102	61.9	15,963	3,393	21.3	19,356	2,516	13.0	21,872	3,644	16.7
3	South Boston,	13,309	3,603	27.1	16,912	8,009	47.4	24,921	4,442	17.8	29,363	9,852	33.6
4	Roxbury,	18,364	105	0.6	18,469	6,668	36.1	25,137	3,289	13.1	28,426	6,327	22.3
5	Dorchester,	7,969	371	4.7	8,340	1,429	17.1	9,769	948	9.7	10,717	1,544	14.4
6	West Roxbury,	–	–	–	4,812	1,498	31.1	6,310	602	9.5	6,912	1,771	25.6
7	Brighton,	2,356	539	22.9	2,895	480	16.6	3,375	479	14.2	3,854	1,113	28.9
8	Charlestown,	17,216	4,484	26.0	21,700	3,365	15.5	25,065	1,334	5.3	26,399	1,924	7.3
9	Total, Boston,	182,796	32,591	17.8	215,387	32,109	14.9	247,496	21,130	8.5	268,626	23,873	8.9
10	Somerville,	3,540	2,266	64.0	5,806	2,219	38.2	8,025	1,328	16.5	9,353	5,332	57.0
11	Chelsea,	6,701	3,450	51.5	10,151	3,244	32.0	13,395	1,008	7.5	14,403	4,144	28.8
12	Everett,	–	–	–	–	–	–	–	–	–	–	–	–
13	Cambridge,	15,215	5,258	34.6	20,473	5,587	27.3	26,060	3,052	11.7	29,112	10,522	36.1
14	Brookline,	2,516	1,221	48.5	3,737	1,427	38.2	5,164	98	1.9	5,262	1,388	26.4
15	Malden,	3,520	1,072	30.5	4,592	1,273	27.7	5,865	975	16.6	6,840	527	7.7
16	Medford,	3,749	854	22.8	4,603	239	5.2	4,842	*3	*0.1	4,839	878	18.1
17	Revere,	935	*142	*15.2	793	128	16.1	921	*63	*6.8	858	339	39.5
18	Winthrop,	–	–	–	407	137	33.7	544	89	16.4	633	*101	*16.0
19	Total, 6-mile radius,	218,972	46,977	21.4	265,949	46,363	17.4	312,312	27,614	8.8	339,926	49,122	14.4
20	Newton,	5,258	1,510	28.7	6,768	1,614	23.8	8,382	593	7.1	8,975	3,850	42.9
21	Hyde Park,	–	–	–	–	–	–	–	–	–	–	–	–
22	Quincy,	5,017	904	18.0	5,921	857	14.5	6,778	*60	*0.9	6,718	724	10.8
23	Melrose,	1,260	716	56.8	1,976	556	28.1	2,532	333	13.2	2,865	549	19.2
24	Arlington,	2,202	468	21.3	2,670	11	0.4	2,681	79	2.9	2,760	501	18.2
25	Watertown,	2,837	741	26.1	3,578	*308	*8.6	3,270	509	15.6	3,779	547	14.5
26	Belmont,	–	–	–	–	–	–	1,198	81	6.8	1,279	234	18.3
27	Lexington,	1,893	656	34.6	2,549	*220	*8.6	2,329	*109	*4.7	2,220	57	2.6
28	Waltham,	4,464	1,585	35.5	6,049	348	5.8	6,397	499	7.8	6,896	2,169	31.5
29	Winchester,	1,353	448	33.1	1,801	136	7.6	1,937	31	1.6	1,968	677	34.4
30	Woburn,	3,956	1,492	37.7	5,448	839	15.4	6,287	712	11.3	6,999	1,561	22.3
31	Milton,	2,241	415	18.5	2,656	13	0.5	2,669	101	3.8	2,770	*87	*3.1
32	Stoneham,	2,085	433	20.8	2,518	688	27.3	3,206	92	2.9	3,298	1,215	36.8
33	Saugus,	1,552	236	15.2	1,788	236	13.2	2,024	*18	*0.9	2,006	241	12.0
34	Lynn,	14,257	1,456	10.2	15,713	3,370	21.4	19,083	1,664	8.7	20,747	7,486	36.1
35	Nahant,	–	–	–	270	110	40.7	380	*67	*17.6	313	162	51.8
36	Wakefield,	2,407	351	14.6	2,758	449	16.3	3,207	37	1.2	3,244	891	27.5
37	Total, 10-mile radius,	269,754	58,658	21.7	328,412	56,260	17.1	384,672	32,091	8.3	416,763	74,035	17.8

	City or Town.	1870.	Increase. In Numbers.	Increase. Per Cent.	1875.	Increase. In Numbers.	Increase. Per Cent.	1880.	Increase. In Numbers.	Increase. Per Cent.	1885.	Increase. In Numbers.	Increase. Per Cent.	1890.	Increase. In Numbers.	Increase. Per Cent.	1895.	Increase. In Numbers.	Increase. Per Cent.
1	Boston (city proper),	138,781	1,888	1.4	140,669	6,406	1.6	147,075	63	0.0	147,138	14,192	9.6	161,330	3,370	2.1	164,700	2,700	1.6
2	East Boston,	25,516	3,831	15.0	29,347	579	2.0	29,926	1,493	5.0	31,419	5,511	17.5	36,930	6,138	16.6	43,068	7,332	17.0
3	South Boston,	39,215	14,932	38.1	54,147	2,222	4.1	56,369	5,165	9.2	61,534	5,257	8.5	66,791	2,859	4.3	69,650	4,952	7.1
4	Roxbury,	34,753	15,676	45.1	50,429	6,694	13.3	57,123	8,842	15.5	65,965	12,446	18.9	78,411	15,686	20.0	94,097	15,996	17.0
5	Dorchester,	12,261	3,527	28.8	15,788	2,102	13.3	17,890	2,827	15.8	20,717	8,921	44.3	29,638	13,302	44.9	42,940	13,150	30.6
6	West Roxbury,	8,683	3,100	35.7	11,783	2,249	19.1	14,032	3,392	24.2	17,424	7,573	43.5	24,997	7,931	31.7	32,928	10,702	32.5
7	Brighton,	4,967	1,233	24.8	6,200	493	8.0	6,693	1,830	27.3	8,523	3,509	41.2	12,032	3,654	30.4	15,686	4,264	27.2
8	Charlestown,	28,323	5,233	18.5	33,556	175	0.5	33,731	3,912	11.7	37,673	675	1.8	38,348	3,285	8.6	41,633	2,287	5.5
9	Total, Boston,	292,499	49,420	16.9	341,919	20,920	6.1	362,839	27,554	7.6	390,393	58,084	14.9	448,477	56,225	12.5	504,702	61,383	12.2
10	Somerville,	14,685	7,183	48.9	21,868	3,065	14.0	24,933	5,038	20.2	29,971	10,181	34.0	40,152	11,431	28.5	51,583	11,792	22.9
11	Chelsea,	18,547	2,190	11.8	20,737	1,045	5.0	21,782	3,927	18.0	25,709	2,200	8.6	27,909	3,066	11.0	30,975	3,125	10.1
12	Everett,	2,220	1,431	64.5	3,651	508	13.9	4,159	1,666	40.1	5,825	5,243	90.0	11,068	6,682	60.4	17,750	6,950	39.2
13	Cambridge,	39,634	8,204	20.7	47,838	4,831	10.1	52,669	6,989	13.3	59,658	10,370	17.4	70,028	10,889	15.5	80,917	11,483	14.2
14	Brookline,	6,650	25	0.4	6,675	1,382	20.7	8,057	1,139	14.1	9,196	2,907	31.6	12,103	3,535	29.2	15,638	3,792	24.2
15	Malden,	7,367	3,476	47.2	10,843	1,174	10.8	12,017	4,390	36.5	16,407	6,624	40.4	23,031	7,209	31.3	30,240	8,260	27.3
16	Medford,	5,717	910	15.9	6,627	946	14.3	7,573	1,469	19.1	9,042	2,037	22.5	11,079	3,733	33.7	14,812	4,788	32.3
17	Revere,	1,197	406	33.9	1,603	660	41.2	2,263	1,374	60.7	3,637	2,031	55.8	5,668	2,039	36.0	7,707	2,924	37.9
18	Winthrop,	532	95	17.9	627	416	66.3	1,043	327	31.4	1,370	1,356	99.0	2,726	1,057	38.8	3,783	1,513	40.0
19	Total, 6-mile radius,	389,048	73,340	18.8	462,388	34,947	7.6	497,335	53,873	10.8	551,208	101,033	18.4	652,241	105,866	16.2	758,107	116,010	15.3
20	Newton,	12,825	3,280	25.6	16,105	890	5.5	16,995	2,764	16.3	19,759	4,620	23.4	24,379	4,091	16.8	28,470	7,231	25.4
21	Hyde Park,	4,136	2,180	52.7	6,316	772	12.2	7,088	1,288	18.2	8,376	1,817	21.7	10,193	2,107	20.7	12,300	2,400	19.5
22	Quincy,	7,442	1,713	23.0	9,155	1,415	15.5	10,570	1,575	14.9	12,145	4,578	37.7	16,723	5,417	32.4	22,140	6,686	30.2
23	Melrose,	3,414	576	16.9	3,990	570	14.3	4,560	1,541	33.8	6,101	2,418	39.6	8,519	3,137	36.8	11,656	3,369	28.9
24	Arlington,	3,261	645	19.8	3,906	194	5.0	4,100	573	14.0	4,673	956	20.5	5,629	944	16.8	6,573	1,577	24.0
25	Watertown,	4,326	773	17.9	5,099	327	6.4	5,426	812	15.0	6,238	835	13.4	7,073	478	6.8	7,551	1,449	19.2
26	Belmont,	1,513	424	28.0	1,937	*322	*16.6	1,615	24	1.5	1,639	459	28.0	2,098	530	25.3	2,628	1,047	39.8
27	Lexington,	2,277	228	10.0	2,505	*45	*1.8	2,460	258	10.5	2,718	479	17.6	3,197	448	14.0	3,645	765	21.0
28	Waltham,	9,065	902	10.0	9,967	1,745	17.5	11,712	2,897	24.7	14,609	4,098	28.1	18,707	2,993	16.0	21,700	3,000	13.8
29	Winchester,	2,645	454	17.2	3,099	703	22.7	3,802	588	15.5	4,390	471	10.7	4,861	2,069	42.6	6,930	1,420	20.5
30	Woburn,	8,560	1,008	11.8	9,568	1,363	14.2	10,931	819	7.5	11,750	1,749	14.9	13,499	1,202	8.9	14,701	2,102	14.3
31	Milton,	2,683	55	2.0	2,738	468	17.1	3,206	349	10.9	3,555	723	20.3	4,278	1,522	35.6	5,800	1,550	26.7
32	Stoneham,	4,513	471	10.4	4,984	*94	*1.9	4,890	769	15.7	5,659	496	8.8	6,155	917	14.9	7,072	1,054	11.9
33	Saugus,	2,247	331	11.7	2,578	47	1.8	2,625	230	8.8	2,855	818	28.7	3,673	965	26.3	4,638	1,087	23.4
34	Lynn,	28,233	4,367	15.5	32,600	5,674	17.4	38,274	7,593	19.8	45,867	9,860	21.5	55,727	5,419	9.7	61,146	11,394	18.6
35	Nahant,	475	291	61.3	766	42	5.5	808	*171	*21.2	637	243	38.1	880	245	27.8	1,125	130	11.6
36	Wakefield,	4,135	1,214	29.4	5,349	198	3.7	5,547	513	9.2	6,060	922	15.2	6,982	1,137	16.3	8,119	1,461	18.0
37	Total, 10-mile radius,	490,798	92,252	18.8	583,050	48,894	8.4	631,944	76,295	12.1	708,239	136,575	19.3	844,814	139,487	16.5	984,301	163,732	16.6

	City or Town.	1900.	Increase. In Numbers.	Increase. Per Cent.	1905.	Increase. In Numbers.	Increase. Per Cent.	1910.	Increase. In Numbers.	Increase. Per Cent.	1915.	Increase. In Numbers.	Increase. Per Cent.	1920.	Increase. In Numbers.	Increase. Per Cent.	1925.	Increase. In Numbers.	Increase. Per Cent.	1930.	
1	Boston (city proper),	167,400	2,700	1.6	170,100	2,700	1.6	172,800	2,700	1.6	175,500	2,700	1.5	178,200	2,700	1.5	180,900	2,800	1.5	183,700	1
2	East Boston,	50,400	7,459	14.8	57,859	7,117	12.3	64,976	6,173	9.5	71,149	4,263	6.0	75,412	3,788	5.0	79,200	3,600	4.5	82,800	2
3	South Boston,	74,602	3,350	4.5	77,952	2,639	3.4	80,591	2,537	3.1	83,128	2,132	2.6	85,260	2,030	2.4	87,290	1,910	2.2	89,200	3
4	Roxbury,	110,093	13,211	12.0	123,304	10,481	8.5	133,785	7,665	5.7	141,450	5,740	4.1	147,190	5,010	3.4	152,200	4,900	3.2	157,100	4
5	Dorchester,	56,090	15,705	28.0	71,795	17,374	24.2	89,169	19,851	22.3	109,020	23,112	21.2	132,132	25,868	19.6	158,000	28,500	18.0	186,500	5
6	West Roxbury,	43,630	12,653	29.0	56,283	14,352	25.5	70,635	16,065	22.7	86,700	17,340	20.0	104,040	18,360	17.6	122,400	19,500	15.9	141,900	6
7	Brighton,	19,950	5,287	26.5	25,237	6,461	25.6	31,698	7,766	24.5	39,464	9,116	23.1	48,580	10,220	21.0	58,800	11,100	18.9	69,900	7
8	Charlestown,	43,920	1,560	3.6	45,480	1,320	2.9	46,800	1,020	2.2	47,820	780	1.6	48,600	600	1.2	49,200	400	0.8	49,600	8
9	Total, Boston,	566,085	61,925	10.9	628,010	62,444	9.9	690,454	63,777	9.2	754,231	65,183	8.6	819,414	68,576	8.4	887,990	72,710	8.2	960,700	9
10	Somerville,	63,375	11,305	17.8	74,680	11,120	14.9	85,800	10,530	12.3	96,330	10,530	10.9	106,860	10,140	9.5	117,000	9,900	8.5	126,900	10
11	Chelsea,	34,100	3,190	9.4	37,290	3,520	9.4	40,810	3,740	9.2	44,550	3,960	8.9	48,510	4,290	8.8	52,800	4,600	8.7	57,400	11
12	Everett,	24,700	8,052	32.6	32,752	9,007	27.5	41,759	10,216	24.5	51,975	11,383	21.9	63,358	12,542	19.8	75,900	13,700	18.1	89,600	12
13	Cambridge,	92,400	12,320	13.3	104,720	13,160	12.6	117,880	14,000	11.9	131,880	14,840	11.3	146,720	15,680	10.7	162,400	16,500	10.2	178,900	13
14	Brookline,	19,430	4,690	21.1	24,120	5,789	24.0	29,909	7,118	23.8	37,027	8,701	23.5	45,728	10,522	23.0	56,250	12,350	22.0	68,600	14
15	Malden,	38,500	9,000	23.4	47,500	9,250	19.5	56,750	10,000	17.6	66,750	11,348	17.0	78,098	12,902	16.5	91,000	14,800	16.3	105,800	15
16	Medford,	19,600	5,950	30.4	25,550	7,350	28.8	32,900	9,541	29.0	42,441	12,393	29.2	54,834	15,166	27.7	70,000	18,000	25.7	88,000	16
17	Revere,	10,631	3,933	37.0	14,564	5,214	35.8	19,778	6,586	33.3	26,364	8,120	30.8	34,484	9,766	28.3	44,250	11,350	25.6	55,600	17
18	Winthrop,	5,296	1,854	35.0	7,150	2,145	30.0	9,295	2,455	26.4	11,750	2,700	23.0	14,450	3,150	21.8	17,600	3,700	21.0	21,300	18
19	Total, 6-mile radius,	874,117	122,219	14.0	996,336	128,999	12.9	1,125,335	137,963	12.3	1,263,298	149,158	11.8	1,412,456	162,734	11.5	1,575,190	177,610	11.3	1,752,800	19
20	Newton,	35,701	8,854	24.8	44,555	10,426	23.4	54,981	11,711	21.3	66,692	12,138	18.2	78,830	11,830	15.0	90,660	12,040	13.3	102,700	20
21	Hyde Park,	14,700	2,730	18.6	17,430	3,150	18.1	20,580	3,910	19.0	24,490	4,947	20.2	29,437	6,263	21.3	35,700	7,900	22.1	43,600	21
22	Quincy,	28,826	7,956	27.6	36,782	9,208	25.0	45,990	10,395	22.6	56,385	9,835	17.4	66,220	9,380	14.2	75,600	8,800	11.6	84,400	22
23	Melrose,	15,025	3,700	24.6	18,725	4,100	21.9	22,825	4,475	19.6	27,300	5,100	18.7	32,400	5,850	18.1	38,250	6,550	17.1	44,800	23
24	Arlington,	8,150	1,793	22.0	9,943	2,107	21.2	12,050	2,500	20.7	14,550	2,925	20.1	17,475	3,325	19.0	20,800	3,800	18.3	24,600	24
25	Watertown,	9,000	1,755	19.5	10,755	2,151	20.0	12,906	2,672	20.7	15,578	3,303	21.2	18,881	3,919	20.8	22,800	4,500	19.7	27,300	25
26	Belmont,	3,675	1,275	34.7	4,950	1,634	33.0	6,584	1,991	30.2	8,575	2,425	28.3	11,000	2,800	25.5	13,800	3,500	[illegible]	17,300	26
27	Lexington,	4,410	865	19.6	5,275	1,000	19.0	6,275	1,155	18.4	7,430	1,295	17.4	8,725	1,475	16.9	10,200	1,700	16.7	11,900	27
28	Waltham,	24,700	5,607	22.7	30,307	6,607	21.8	36,914	7,678	20.8	44,592	8,785	19.7	53,377	9,623	18.0	63,000	10,700	17.0	73,700	28
29	Winchester,	8,350	1,775	21.3	10,125	2,100	20.7	12,225	2,500	20.4	14,725	2,925	19.9	17,650	3,350	19.0	21,000	3,800	18.1	24,800	29
30	Woburn,	16,803	2,453	14.6	19,256	2,850	14.8	22,106	3,316	15.0	25,422	3,915	15.4	29,337	4,663	15.9	34,000	5,400	15.9	39,400	30
31	Milton,	7,350	1,900	25.8	9,250	2,294	24.8	11,544	2,724	23.6	14,268	3,167	22.2	17,435	3,565	20.4	21,000	4,100	19.5	25,100	31
32	Stoneham,	8,126	1,219	15.0	9,345	1,411	15.1	10,756	1,635	15.2	12,391	1,896	15.3	14,287	2,213	15.5	16,500	2,500	15.2	19,000	32
33	Saugus,	5,725	1,300	22.7	7,025	1,553	22.1	8,578	1,822	21.2	10,400	2,125	20.4	12,525	2,475	19.8	15,000	2,850	19.0	17,850	33
34	Lynn,	72,540	13,260	18.3	85,800	15,600	18.2	101,400	17,120	16.9	118,520	18,370	15.5	136,890	20,310	14.8	157,200	22,500	14.3	179,700	34
35	Nahant,	1,255	225	17.9	1,480	265	17.9	1,745	305	17.5	2,050	355	17.3	2,405	395	16.4	2,800	425	15.2	3,225	35
36	Wakefield,	9,580	1,868	19.5	11,448	2,381	20.8	13,829	3,015	21.8	16,844	3,756	22.3	20,600	4,400	21.4	25,000	5,000	20.0	30,000	36
37	Total, 10-mile radius,	1,148,033	180,754	15.7	1,328,787	197,836	14.9	1,526,623	216,887	14.2	1,743,510	236,420	13.6	1,979,930	258,570	13.1	2,238,500	283,375	12.7	2,521,875	37

* Decrease.

Incr

In
nbe

2,7

6.

Population of Boston, New York, Philadelphia and Chicago, within a Radius of Ten and Fifteen Miles from the Business Centre.

Ten-mile Radius.

CITY.	Area of Land Surface, Square Miles.	1820.	1830.	1840.	1850.	1855.	1860.	1865.	1870.	1875.	1880.	1885.	1890.
Boston, ...	223	84,362	115,051	167,843	*269,754	*328,412	*384,672	*416,763	*490,798	*583,050	*631,944	*708,239	*844,814
New York, ...	256	148,402	236,842	394,935	720,091	-	1,245,104	-	1,626,119	-	2,131,051	-	2,821,802
Philadelphia, ...	290	149,609	203,136	275,409	437,918	-	605,614	-	726,247	-	924,458	-	1,162,577
Chicago, ...	166	-	250	5,455	31,374	-	117,601	-	310,996	-	550,618	-	1,075,158

Fifteen-mile Radius.

CITY.	Area of Land Surface, Square Miles.	1820.	1830.	1840.	1850.	1855.	1860.	1865.	1870.	1875.	1880.	1885.	1890.
Boston, ...	518	126,217	160,693	220,792	338,259	406,997	468,757	499,628	582,436	681,040	736,015	815,312	962,618
New York, ...	549	179,043	278,352	439,239	785,001	-	1,360,401	-	1,795,616	-	2,354,092	-	3,136,543
Philadelphia, ...	674	176,963	233,272	311,814	482,317	-	660,683	-	796,780	-	1,012,712	-	1,275,434
Chicago, ...	383	-	250	5,877	34,560	-	124,815	-	321,294	-	576,866	-	1,153,758

* These populations are the aggregate of the cities and towns within ten miles of the State House, and exceed the populations within a ten-mile circle by an amount increasing from 2,434 in 1850 to 14,635 in 1890.

*Population of London, with and without Suburbs.**

	1821.	1831.	1841.	1851.	1861.	1871.	1881.	1891.
Inner ring, or municipal London,† . .	1,378,947	1,654,994	1,948,417	2,362,236	2,803,847	3,253,785	3,815,544	4,211,056
Outer ring, . . .	–	–	–	–	418,873	631,856	951,117	1,422,276
Total, or "Greater London," . . .	–	–	–	–	3,222,720	3,885,641	4,766,661	5,633,332

* These statistics of the population of London are taken from the "Report of the Royal Commission on Metropolitan Water Supply, Appendices to Minutes of Evidence," pages 131, 132. They were presented to the Commission by Mr. A. R. Binnie, chief engineer to the London county council.

† The area of inner or registration London is given by the registrar-general as 121 square miles, and includes tidal water and foreshore.

Population of Berlin, with and without Suburbs.

	1860.	1865.	1870.	1875.	1880.	1885.	1890.
Berlin, ...	493,400	657,690	760,000	966,858	1,122,330	1,291,359	1,548,279
Berlin and suburbs, .	575,000	760,000	887,000	1,131,119	1,314,286	1,557,778	1,956,466

The population of Berlin and of Berlin and suburbs was taken from several sources, and is believed to be accurate, with the exception of the combined population of Berlin and suburbs for 1860, 1865 and 1870. The available statistics of the population of the suburbs for these years were incomplete, and the figures are therefore only approximate.

Appendix No. 2.

PRESENT AND FUTURE CONSUMPTION OF WATER IN THE METROPOLITAN DISTRICT.

By Dexter Brackett, C.E.

Boston, Nov. 1, 1894.

Frederic P. Stearns, C.E., *Chief Engineer, State Board of Health.*

Sir: — The following report is submitted as the result of my investigations in regard to the present and future consumption of water per inhabitant in the Boston metropolitan district.

REPORT.

The earlier works built for furnishing public water supplies in the United States were designed upon the assumption that a supply of 30 gallons per inhabitant would prove ample for all requirements. The experience of a few years proved that this estimate of the quantity required was much lower than the actual quantity demanded to meet the wants of the communities, and the constant tendency during the past forty years has been toward an increase in the quantity used. The following table, showing per capita the consumption in various cities of the United States, very clearly illustrates this point.

It will be noticed that in almost every city there has been an increase in the consumption per capita during the past twenty years, and in many instances this increase has been enormous. In Philadelphia the population has increased about 25 per cent. since 1880, while the quantity of water used has increased about 300 per cent., and 150 gallons per capita are now required for daily use. The increase in the consumption in Boston has not been in so large a proportion, owing to the efforts which have from time to time been made to control the waste, which forms a large proportion of the total consumption.

TABLE No. 1.—*Daily Average Consumption of Water in gallons per capita per day in various cities in the United States.*

Population.

YEARS.	Boston, Cochituate Works.	Boston, Mystic Works.	Chicago.	Philadelphia.	Brooklyn.	St. Louis.	Cincinnati.	Cleveland.	Detroit.
1850, . .	139,800	–	29,963	121,376	96,838	77,860	115,435	17,034	21,019
1860, . .	177,900	–	109,260	565,529	266,661	160,773	161,044	43,417	45,619
1870, . .	225,100	87,071	298,977	674,022	396,099	310,864	216,239	92,829	79,577
1880, . .	306,000	107,700	503,185	847,170	566,663	350,518	255,139	160,146	116,340
1890, . .	410,130	117,500	1,099,850	1,046,964	806,343	451,770	296,908	261,353	205,876

Gallons per Capita.

YEARS.	Boston, Cochituate Works.	Boston, Mystic Works.	Chicago.	Philadelphia.	Brooklyn.	St. Louis.	Cincinnati.	Cleveland.	Detroit.
1850, . .	42	–	–	–	–	–	20	–	–
1855, . .	64	–	–	–	–	–	25	–	44
1860, . .	97	–	43	36	–	–	30	14	52
1865, . .	66	27	42	50	29	–	29	22	55
1870, . .	66	44	73	55	47	–	48	31	64
1871, . .	60	56	72	55	47	–	53	36	76
1872, . .	63	70	74	54	53	45	54	40	88
1873, . .	72	77	88	56	59	51	50	43	98
1874, . .	72	73	96	58	54	55	55	45	97
1875, . .	69	86	100	69	59	61	60	44	120
1876, . .	71	80	103	–	57	62	68	49	111
1877, . .	72	75	–	58	59	66	64	56	111
1878, . .	80	76	123	64	58	67	66	51	110
1879, . .	87	88	–	66	60	72	68	63	125
1880, . .	87	87	112	68	54	72	76	65	130
1881, . .	94	80	–	71	56	76	87	77	145
1882, . .	95	73	110	76	58	76	69	68	132
1883, . .	97	74	–	76	58	75	66	76	146
1884, . .	73	65	114	74	61	63	74	83	159
1885, . .	73	68	116	72	64	67	64	93	176
1886, . .	74	72	118	80	65	73	74	91	176
1887, . .	80	72	120	89	65	73	88	96	197
1888, . .	87	75	119	100	67	74	99	95	204
1889, . .	81	69	123	110	67	73	99	99	172
1890, . .	83	71	127	132	68	78	115	106	155
1891, . .	90	75	135	140	70	83	138	111	144
1892, . .	96	79	134	143	79	89	123	118	140
1893, . .	107	86	147	150	86	96	124	130	148

TABLE I. — *Daily Average Consumption of Water in gallons per capita per day in various cities in the United States* — Concluded.

Population.

Years.	Milwaukee.	Louisville.	Providence.	Lowell.	Fall River.	Cambridge.	Lynn.	New Bedford.	Salem.
1850, . .	20,061	43,194	41,513	33,383	11,524	15,215	14,257	16,443	20,264
1860, . .	45,246	68,033	50,666	36,827	14,026	26,060	19,083	22,300	22,252
1870, . .	71,440	100,753	68,904	40,928	26,766	39,634	28,233	21,320	24,117
1880, . .	115,587	123,758	104,857	59,475	48,961	52,669	38,274	26,845	27,563
1890, . .	204,468	161,129	132,146	77,696	74,398	70,028	55,727	40,733	30,801

Gallons per Capita.

Years.	Milwaukee.	Louisville.	Providence.	Lowell.	Fall River.	Cambridge.	Lynn.	New Bedford.	Salem.
1850, . .	–	–	–	–	–	–	–	–	–
1855, . .	–	–	–	–	–	–	–	–	–
1860, . .	–	–	–	–	–	–	–	–	–
1865, . .	–	18	–	–	–	–	–	–	–
1870, . .	–	23	–	–	–	44	–	–	31
1871, . .	–	21	–	–	–	43	–	–	38
1872, . .	–	22	–	–	–	38	–	–	45
1873, . .	–	22	–	–	–	48	41	–	55
1874, . .	–	24	–	–	12	50	42	–	51
1875, . .	29	24	–	24	18	57	40	–	–
1876, . .	45	27	–	29	25	51	32	–	59
1877, . .	69	29	24	30	26	53	32	–	58
1878, . .	85	30	26	32	25	45	32	–	53
1879, . .	96	33	30	35	27	47	34	–	55
1880, . .	106	42	34	38	28	46	32	–	55
1881, . .	109	56	35	40	30	46	32	86	59
1882, . .	114	47	33	43	36	45	37	82	63
1883, . .	108	52	37	46	31	47	36	78	61
1884, . .	101	56	34	48	26	46	39	72	60
1885, . .	105	62	37	56	26	51	42	85	62
1886, . .	110	65	37	59	27	56	44	86	64
1887, . .	117	64	37	62	25	60	48	85	77
1888, . .	105	62	40	69	28	63	45	88	71
1889, . .	116	67	41	62	27	62	43	89	68
1890, . .	114	71	46	69	28	65	45	98	69
1891, . .	112	78	48	74	30	67	49	92	87
1892, . .	101	81	57	73	27	71	53	88	81
1893, . .	108	75	63	79	27	80	54	91	66

Table No. 2.

Table Showing Average Daily Water Consumption of the Boston Metropolitan District, 1880–1893.

Note.—The figures in the first row represent the total consumption in gallons and those in the second row the consumption in gallons per capita. Numbers printed in *italics* are estimated.

City or Town.	Boston Cochituate Works.	Boston Mystic Works, including Charlestown, Somerville, Chelsea and Everett.	Total Cochituate and Mystic.	Cambridge.	Lynn and Saugus.	Newton.	Malden.	Waltham.	Quincy.	Hyde Park and Milton.	Woburn.	Wakefield and Stoneham.
Date of Introduction of Water.	1848	1864		1856	1871 1887	1876	1870	1873	1884	1885 1890	1873	1883
1880	26,500,000	9,388,000	35,888,000	2,426,000	1,235,000	452,000	*601,000*	410,000	-	-	740,000	-
	87	87	87	46	32	27	*50*	35	-	-	68	-
1881	31,020,000	7,195,000	38,215,000	2,460,000	1,280,000	451,000	*632,000*	450,000	-	-	767,000	-
	94	80	91	46	32	26	*50*	37	-	-	69	-
1882	31,971,000	6,574,000	38,545,000	2,515,000	1,511,000	596,000	*672,000*	524,000	-	-	828,000	-
	96	73	91	46	37	33	*50*	41	-	-	74	-
1883	32,837,000	6,819,000	39,656,000	2,668,000	1,558,000	624,000	*715,000*	602,000	-	-	726,000	-
	97	74	92	47	36	34	*50*	45	-	-	64	-
1884	25,090,000	6,210,000	31,300,000	2,670,000	1,739,000	533,000	*765,000*	519,000	-	-	610,000	*286,000*
	73	65	71	46	39	28	*50*	37	-	-	53	*25*
1885	25,607,000	6,737,000	32,344,000	3,074,000	1,921,000	615,000	*820,000*	529,000	*304,000*	-	693,000	347,000
	73	68	72	52	42	31	*50*	36	*25*	-	59	30
1886	26,628,000	7,400,000	34,028,000	3,458,000	2,116,000	679,000	*875,000*	608,000	*322,000*	170,000	870,000	363,000
	74	72	73	56	44	33	*50*	39	*25*	20	72	30
1887	29,852,000	7,629,000	37,481,000	3,861,000	2,379,000	693,000	*937,000*	544,000	375,000	201,000	889,000	322,000
	80	72	78	61	48	32	*50*	34	27	22	72	26
1888	33,311,000	8,258,000	41,569,000	4,165,000	2,475,000	700,000	*1,005,000*	583,000	425,000	285,000	769,000	390,000
	87	75	84	64	45	31	*50*	31	29	30	60	31
1889	32,070,000	7,830,000	39,900,000	4,189,000	2,450,000	864,000	*1,078,000*	569,000	409,000	333,000	674,000	467,000
	81	69	78	62	43	37	*50*	32	26	34	51	36
1890	33,872,000	8,301,000	42,173,000	4,566,000	2,857,000	985,000	*1,152,000*	626,000	497,000	390,000	777,000	537,000
	83	71	80	65	45	40	*50*	33	30	27	58	41
1891	37,687,000	9,055,000	46,742,000	4,857,000	3,131,000	1,065,000	*1,238,000*	769,000	565,000	498,000	730,000	541,000
	88	73	85	66	51	42	*60*	38	32	33	53	40
1892	41,312,000	9,811,000	51,123,000	5,358,000	3,549,000	1,288,000	*1,243,000	919,000	602,000	564,000	775,000	599,000
	94	76	90	70	55	49	47	43	32	35	55	43
1893	47,453,000	10,743,000	58,196,000	6,181,000	3,744,000	1,370,000	1,451,000	1,055,000	729,000	628,000	900,000	553,000
	105	79	99	78	55	50	51	49	36	37	63	38

* From meter measurements September 1 to Dec. 31, 1892, inclusive

Table No. 2.

Table Showing Average Daily Water Consumption of the Boston Metropolitan District, 1880–1893.

Note. — The figures in the first row represent the total consumption in gallons and those in the second row the consumption in gallons per capita. Numbers printed in *italics* are estimated.

City or Town.	Brookline.	Medford.	Watertown and Belmont.	Melrose.	Revere and Winthrop.	Dedham.	Arlington.	Winchester.	Lexington.	Nahant.	Entire District.	Total Population of Places Supplied.
Date of Introduction of Water.	1875	1870	1885 1887	1870	1884	1881	1873	1873	1884	1885		
1880,	566,000	*378,000*	-	*228,000*	-	-	*205,000*	*190,000*	-	-	43,319,000	584,410
	70	*50*	-	*50*	-	-	*50*	*50*	-	-	74	-
1881,	485,000	*390,000*	-	*237,000*	-	-	*210,000*	*195,000*	-	-	45,772,000	594,030
	59	*50*	-	*50*	-	-	*50*	*50*	-	-	77	-
1882,	494,000	*404,000*	-	*252,000*	-	80,000	*215,000*	*201,000*	-	-	46,837,000	612,270
	59	*50*	-	*50*	-	13	*50*	*50*	-	-	76	-
1883,	547,000	*419,000*	-	*267,000*	-	100,000	*221,000*	*206,000*	-	-	48,309,000	626,000
	64	*50*	-	*50*	-	16	*50*	*50*	-	-	77	-
1884,	568,000	*435,000*	-	*285,000*	-	115,000	*227,000*	*213,000*	-	-	40,265,000	653,310
	64	*50*	-	*50*	-	18	*50*	*50*	-	-	62	-
1885,	657,000	*452,000*	-	*305,000*	*250,000*	129,000	*233,000*	*219,000*	*136,000*	-	43,028,000	691,580
	71	*50*	-	*50*	*50*	19	*50*	*50*	*50*	-	62	-
1886,	698,000	*470,000*	146,000	*325,000*	*277,000*	136,000	*244,000*	*224,000*	*139,000*	*34,000*	46,182,000	730,350
	72	*50*	23	*50*	*50*	20	*50*	*50*	*50*	*50*	63	-
1887,	763,000	*490,000*	158,000	† 482,000	*309,000*	155,000	*252,000*	*229,000*	*144,000*	*36,000*	50,700,000	755,890
	75	*50*	24	68	*50*	23	*50*	*50*	*50*	*50*	67	-
1888,	848,000	*510,000*	212,000	† 499,000	*343,000*	186,000	*260,000*	*233,000*	*149,000*	*39,000*	55,595,000	788,105
	79	*50*	25	66	*50*	27	*50*	*50*	*50*	*50*	71	-
1889,	768,000	*532,000*	284,000	† 524,000	362,000	203,000	*270,000*	*238,000*	*154,000*	*42,000*	54,310,000	817,170
	67	*50*	32	65	48	29	*50*	*50*	*50*	*50*	66	-
1890,	877,000	*554,000*	360,000	† 581,000	427,000	223,000	*281,000*	*243,000*	*160,000*	*44,000*	58,110,000	851,937
	72	*50*	39	68	51	31	*50*	*50*	*50*	*50*	68	-
1891,	979,000	*590,000*	333,000	† 716,000	473,000	212,000	*295,000*	*258,000*	*163,000*	*46,000*	64,201,000	891,313
	76	*50*	35	77	54	29	*50*	*50*	*50*	*50*	72	-
1892,	1,046,000	* 568,000	407,000	† 720,000	543,000	275,000	*308,000*	*273,000*	*167,000*	*49,000*	70,376,000	928,270
	77	45	41	72	58	38	*50*	*50*	*50*	*50*	76	-
1893,	1,214,000	611,000	477,000	† 652,000	723,000	368,000	*319,000*	*290,000*	*171,000*	*51,000*	79,623,000	961,087
	85	46	48	60	73	42	*50*	*50*	*50*	*50*	83	-

* From meter measurements Sept. 7 to Dec. 31, 1892, inclusive. † Pump measurements. ‡ Meter measurements.

Table No. 2 shows the daily average consumption in gallons and the consumption per capita in each of the cities and towns of the metropolitan district since 1880, together with the total consumption and population supplied in each year.

From this table it appears that the works of the city of Boston now furnish between 70 and 75 per cent of the total quantity used in the entire metropolitan district. From 1880 to 1883, inclusive, the daily average consumption of the entire district was from 74 to 77 gallons per capita, but in 1884 the quantity dropped to 62 gallons, from which point there has been a gradual rise, and in 1893 83 gallons were used. The abrupt fall in the consumption in the year 1883 was the result of the introduction of the Deacon waste detection system in Boston.

The figures given for the city of Fall River (Table 1) show a most striking contrast to those of all of the other cities. Here is a city of 75,000 inhabitants, where the daily consumption is only 27 gallons per capita, and where there has been no increase in the amount during the past fifteen years; in fact, taking into consideration the number of consumers rather than the total population, the present consumption per capita is 30 gallons, as compared with 41 gallons in 1877.

The question naturally arises, If 27 gallons per capita are found to be all that are required to meet all demands in a manufacturing city of 75,000 inhabitants, why is double that amount needed in the suburban cities and towns near Boston, and three times that quantity for the entire metropolitan district? In order to intelligently answer this question, and also to determine what may be considered as proper quantities to be used for domestic, manufacturing and public purposes in designing works to meet the requirements of future years, a careful study has been made of the conditions which obtain and of the quantities which are actually used for various purposes in different cities and towns.

In the first place, it may be stated that the low consumption in Fall River is due in a great measure to the fact that the use of meters on a large percentage of the services has been the practice of the department ever since the building of the works; and a further cause is that the use for manufacturing purposes is small, most of the manufacturers taking their supply from the river and not from the city works. The total consumption for mechanical purposes during the year 1892, as measured by meters, was about 2 gallons per head per day.

The water used in any city or town may be sub-divided under four heads: —

1. Quantity used for domestic purposes.
2. Quantity used for trade and manufacturing purposes.
3. Quantity used for public purposes.
4. Quantity wasted.

1. *Quantity Used for Domestic Purposes.*

Under the first head should be included not only the household uses of the inhabitants, but also the quantity required for provision stores, fish markets, laundries, stables, — in fact, all the requirements of a residential community, with the exception of the public uses of fountains, street watering, fires, etc

Table No. 3 embodies the results of data collected, showing the actual consumption per capita for domestic use of different classes of people in a number of cities, as determined by yearly meter records: —

TABLE No. 3.

Consumption per Capita for Domestic use in Boston, Brookline, Newton, Fall River, Worcester and London, Eng., as determined by Meter Measurement.

City or Town.	Number of Houses.	Number of Families.	Number of Persons.	Consumption, Gallons per —		Remarks.
				Family.	Capita.	
Boston, . . .	31	402	1,461	221	59	Highest-cost apartment houses in the city.
Boston, . . .	46	628	2,524	185	46	First-class apartment houses.
Boston, . . .	223	2,204	8,432	123	32	Moderate-class apartment houses.
Boston, . . .	39	413	1,844	80	16.6	Poorest-class apartment houses.
Boston, . . .	339	3,647	14,261	139	35.6	Average of all apartment houses supplied by meter.
Boston, . . .	40	–	1,699	–	46.1	Boarding-houses.
Brookline, . .	–	828	4,140	221.5	44.3	Average of all dwellings supplied by meter.
Newton, . .	490	490	2,450	132.5	26.5	All houses supplied with modern plumbing.
Newton, . .	–	619	3,005	–	6.6	These families have but one faucet each.
Newton, . .	–	278	1,390	34.5	6.9	These families have but one faucet each.
Fall River, . .	28	34	170	127.5	25.5	The most expensive houses in the city.
Fall River, . .	64	148	740	42.0	8.4	Average class of houses, generally having bath and water-closet.
Worcester, . .	–	20,514	90,942	–	16.8	Whole domestic consumption
Worcester, . .	–	81	327	80.2	19.9	Woodland Street, best class of houses.
Worcester, . .	–	37	187	118.1	23.4	Cedar Street, best class of houses.
Worcester, . .	–	93	447	95.0	19.8	Elm Street, houses of moderate cost.
Worcester, . .	–	245	1,104	55.1	12.2	Southbridge Street, cheaper houses.
Worcester, . .	–	229	809	55.0	15.6	Austin Street, cheaper houses.
London (Eng.), .	1,169	–	8,183	–	25.5	Houses renting from $250 to $600; each having bath and two water-closets.
London (Eng.), .	727	–	5,089	–	18.6	Middle class, average rental $200.

All of the examples cited in Boston are of apartment and boarding-houses, and do not include any private stables or conservatories; and the

proportion of hand hose per capita is small. The average number of persons per house is about 40. The consumption per capita varies from 59 gallons in the most expensive houses, provided with all the modern conveniences of water supply, to 16.6 gallons in the cheapest class of apartment houses. The average amount used per capita by the 15,960 persons was 36.7 gallons.

In the town of Brookline the average consumption per capita was 44.3 gallons, including the amount used for private stables, conservatories, lawns, etc. It is probable that the domestic use of water, not including waste, is larger in Brookline than in any of the suburban towns about Boston.

In Newton 490 families show a consumption of 26.5 gallons per capita in 1892, assuming 5 persons per family. These are all in modern houses, costing from $5,000 to $15,000, containing all modern plumbing conveniences, but with few stables, and the houses are on smaller estates than many of those in Brookline. The total quantity used in Newton through 3,566 meters during the year 1892 was 175,000 gallons; and, taking an estimated population of 18,000 (which is thought to be very nearly correct), we find the daily average per head to have been 26.5 gallons, including the quantity used for stores and stables.

In Worcester and Fall River the quantity used is very much smaller. The daily average consumption of 90,942 people in Worcester, as determined by meter measurements during 1892, was but 16.8 gallons, and 70,000 people in Fall River during the same year used daily but 11.2 gallons per capita. Thirty-four families living in some of the most expensive houses of Fall River, some of these having private stables, used but 127 gallons per family, or 25.5 gallons per capita; while 148 families residing in houses of moderate cost, generally provided with water-closet and bath, used but 42 gallons each, or 8.4 gallons per person.

The figures given for London were taken from the report of the Royal Commission on the Water Supply of the Metropolis. The consumption per capita in English cities is generally much smaller than in the United States, but these figures indicate that the actual quantities used in buildings having water fixtures of similar character are the same there as in our cities.

In the above examples the quantities given are the records of actual use, as determined by meters on every service; and the amount used for manufacturing purposes, together with the quantity used and wasted from the street mains and services, is not included. The quantities vary from 11.2 gallons in Fall River to 44.3 gallons in Brookline. As most if not all of the meters after a few years' use fail to register the total quantity used, an addition of probably 10 per cent. should be made to these quantities, making them 12.3 and 48.7 gallons respectively

Although the number of water fixtures used in dwellings is increasing from year to year, I am of the opinion that, taking into consideration the

class of population occupying the metropolitan district, the quantity required for domestic use should not, at the present time, exceed 30 gallons per capita where the premises are generally metered.

2. Quantity used for Mechanical, Trade and Manufacturing Purposes.

The principal users of water for mechanical purposes are railroads, gas, electric light and power companies, sugar refineries, breweries, cordage and rubber works, shipping, slaughtering establishments and elevators.

The use of water for mechanical purposes shows a great variation in different communities. In residential districts like Brookline and Newton but little water is required in addition to the domestic use; but in Boston, Cambridge and Somerville there is a large and growing demand for water for mechanical purposes. As all of the large users of water for trade and mechanical purposes take their supplies through meters, we can determine the quantities used for different purposes. Table 4 shows the daily quantities of metered water used for trade and mechanical purposes from the Cochituate and Mystic works and in Cambridge, during the year 1892: —

TABLE NO. 4.

Metered Water used for Trade and Mechanical Purposes in Boston, Chelsea, Somerville, Everett and Cambridge, in 1892.

NAME OF BUSINESS.	DAILY AVERAGE AMOUNT IN GALLONS.		
	Cochituate and Mystic.	Cambridge.	Total.
Sugar refineries,	729,000	200,200	929,200
Bakeries,	13,030	–	13,030
Breweries and bottling,	420,940	–	420,940
Chemical works,	87,270	–	87,270
Distilleries,	10,780	–	10,780
Electrical companies,	320,500	101,600	422,100
Elevators and motors,	1,337,700	–	1,337,700
Factories,	1,177,500	296,500	1,414,000
Gas companies,	355,530	–	355,530
Iron works,	83,730	–	83,730
Laundries,	91,660	–	91,660
Marble and stone works,	52,950	–	52,950
Markets,	12,050	–	12,050
Mills and engines,	62,680	–	62,680

TABLE No. 4 — Concluded.

Metered Water used for Trade and Mechanical Purposes in Boston, Chelsea, Somerville, Everett and Cambridge, in 1892 — Concluded.

NAME OF BUSINESS.	DAILY AVERAGE AMOUNT IN GALLONS.		
	Cochituate and Mystic.	Cambridge.	Total.
Offices, stores and shops,	2,458,700	–	2,458,700
Oil works,	17,250	–	17,250
Restaurants,	164,800	–	164,800
Shipping,	351,700	–	351,700
Slaughter houses,	374,500	138,300	512,800
Stables,	309,600	–	309,600
Street railways,	422,900	–	422,900
Steam railways,	1,604,600	178,800	1,783,400
Saloons,	120,500	–	120,500
Tanneries,	16,800	–	16,800
Wharves,	39,800	–	39,800
Fish stores,	18,200	–	18,200
Greenhouses,	9,550	–	9,550
Hotels (transient),	596,200	–	596,200
Theatres,	36,100	–	36,100
Miscellaneous,	–	255,000	255,000
Totals,	11,236,520	1,170,400	12,406,920

In addition to the water metered for manufacturing and trade, there is quite a large quantity paid for by schedule rates. This amount cannot be accurately determined, but it has been estimated in the following manner: the actual amount received in Boston for the unmetered water during the year 1892 was $0.0813 per thousand gallons, and this price has been applied to the amounts received for different purposes, to estimate the proportionate quantity used. This method I think gives fairly accurate results. Applying it to the receipts for 1880 and 1892, we find that in 1880 16.08 gallons of unmetered water were used for manufacturing and trade purposes, to which must be added 9.27 gallons which were metered, giving a total of 25.35 gallons used for these purposes. In 1892 the total for the same purposes was 30.27 gallons, of which 7.67 gallons were not metered. Table No. 5 shows in detail the number of gallons per inhabitant, both metered and unmetered, which were required for different purposes in 1880 and 1892: —

TABLE No. 5.

Table showing Consumption in Gallons per Capita for Various Purposes from the Cochituate Works, in 1880 and 1892.

	1880.			1892.		
	Metered.	Un-metered.	Total.	Metered.	Un-metered.	Total.
Manufactures and Trade.						
Office buildings and stores,	0.844	10.200	11.044	5.63	5.54	11.17
Steam railroads,	1.139	-	1.139	2 26	-	2.26
Sugar refineries,	0.811	-	0.811	1.70	-	1.70
Factories, machine shops, mills and engines.	0.966	2.120	3.086	2.15	-	2.15
Iron works and foundries,	0.573	-	0.573	0.24	-	0.24
Marble and stone works,	0.143	-	0.143	0.12	-	0.12
Gas companies,	0.324	-	0.324	0.75	-	0.75
Electric light companies,	-	-	-	0.69	-	0.69
Breweries,	0.556	-	0.556	0.89	-	0.89
Oil and chemical works,	0.214	-	0.214	0.19	-	0.19
Laundries,	-	0.150	0.150	0.15	0.35	0.50
Restaurants,	0.129	0.650	0.779	0.37	0.29	0.66
Stables,	0.443	-	0.443	0.60	-	0.60
Steamers and shipping,	0.325	1.000	1.325	0.82	0 08	0.90
Elevators and motors,	1.033	-	1.033	2.95	-	2.95
Street railways,	-	-	-	0.90	-	0.90
Saloons,	-	1.500	1.500	0.27	0.89	1.16
Hotels,	1.454	0.150	1.604	1.55	0.07	1.62
Theatres and halls,	-	-	-	0.10	0.09	0.19
Markets and cellars,	-	0.150	0.150	-	-	-
Greenhouses,	-	0.160	0.160	-	0.08	0.08
Miscellaneous,	0.314	-	0.314	0.27	0.28	0.55
Totals,	9.268	16.080	25.348	22.60	7.67	30.27
Domestic Uses.						
Apartment hotels,	0.047	5.850	5.897	1.72	12.34	14.06
Dwelling-houses,	-	50.000	50.000	-	43.90	43.90
Stables,	-	1.500	1.500	-	1.38	1.38
Hand hose,	-	1.250	1.250	-	2.25	2.25
Club houses,	-	0.040	0.040	0.18	0.07	0.25
Churches,	-	0.250	0.250	-	0.18	0.18
Miscellaneous,	-	-	-	-	0.22	0.22
Totals,	0.047	58.890	58.937	1.90	60.34	62.24
Public Uses.						
Hospitals,	-	0 200	0.200	0.30	0.21	0.51
Schools,	0.505	0.400	0.905	0.30	0.12	0.42
City, State and Government buildings,	-	0.400	0.400	0.83	0.52	1.35
Urinals, fountains, etc.,	-	-	-	-	0.14	0.14
Miscellaneous,	-	0.500	0.500	-	-	-
Totals,	0.505	1.500	2.005	1.43	0.99	2.42

That the use of water for mechanical and trade purposes is increasing at a more rapid rate than the population is evident from the fact that 30.27 gallons were used in 1892, while 25.35 gallons sufficed in 1880. In order to illustrate this fact more forcibly, I have selected from Table No. 5 the quantities used for the more important manufacturing and mechanical uses in 1880 and 1892, and have grouped them in the following table. All of the water used by these classes of takers is metered: —

Gallons per Capita.

	1880.	1892.
Steam railroads,	1.14	2.26
Sugar refineries,	.81	1.70
Gas works,	.32	.75
Electric light and power,	–	.69
Breweries,	.56	.89
Elevators,	1.03	2.95
Totals,	3.86	9.24

The daily quantity used in 1880 for the above purposes was 1,242,900 gallons, and in 1892 3,973,200 gallons, — a difference of 2,731,000 gallons, or more than 20 per cent. of the total increase in the consumption of the works.

The present requirements for trade and mechanical purposes in Boston, Somerville, Chelsea, Cambridge and Everett is about 25 gallons per capita. In considering the whole metropolitan district this amount per head should be slightly reduced; but in view of the fact that there is a constantly increasing demand for water for these purposes, and also considering that an allowance of about ten per cent. should be made to cover shortage in meter measurement, I think that at least 35 gallons per capita should be allowed in providing for future years.

3. *Amount required for Public Purposes, including Public Buildings, Institutions, Hospitals, Schools, Street Sprinkling, Flushing Sewers, Ornamental and Drinking Fountains and Fires.*

The metered consumption of the Cochituate and Mystic works for the year 1892, for public buildings, schools and hospitals, was 1.5 gallons, and the unmetered quantity I estimate at 0.8 gallons, making 2.3 gallons per capita used for these purposes. A careful study of the quantity required for different public uses, based upon such information as I

have been able to obtain, gives the following requirements for the different purposes.

	Gallons.
Public buildings, schools and hospitals,	2.30
Street sprinkling,	1.00
Flushing sewers, public urinals,	.10
Ornamental and drinking fountains,	.25
Fires,	.10
Total for public purposes,	3.75

Probably 4 gallons per capita should cover all the requirements for public purposes.

4. Amount Wasted.

Consideration of the preceding statements of the amounts actually required for domestic, trade, manufacturing and public uses, in connection with the quantities given in tables Nos. 1 and 2, shows that a very large percentage of the total consumption in most of the large cities and towns is wasted; and in the quantity wasted I do not include water which is lavishly used, but only that which is either negligently or wilfully permitted to escape from the pipes or otherwise without performing any useful service.

The Deacon waste water meters, which have been used for the measurement and detection of waste in Boston since 1880, furnish conclusive evidence of the existence of an enormous amount of waste. This meter records upon a diagram the rate of flow through the meter at all times of the day or night, and also furnishes a record of the water drawn from the mains during the hours of the night when the legitimate use of water should be very small.

In 1880 a very thorough trial of these meters was made in the Charlestown district. In a residential section containing 21,760 persons the daily consumption per capita was found to be 58.5 gallons, and between the hours of one and four A.M., when the legitimate use was least, it was at the rate of 37.5 gallons per head per day. A careful examination of the street mains and house fixtures was made, and after two or three inspections the meters showed a reduction in the daily average consumption of 20.8 gallons, and in the night rate of 21.7 gallons. The total daily consumption after the inspection was 37.7 gallons, or the same as the night rate before the waste had been stopped. It is noticeable that the reduction in the day and night rate was practically the same.

The use of these meters was in 1883 extended so as to cover the greater part of the residential portion of the city, and at the present time 84 are in use. By their use, aided by a house-to-house inspection, the daily average consumption per capita was reduced from 91.8 gallons in 1883 to 71 gal-

lons in 1884, — a saving of 20.8 gallons per capita. The use of the meters has been continued, but the reduction in the waste which was accomplished in the first experiments in Charlestown and East Boston has not been obtained throughout the city.

Table No. 6 shows the population included in the Deacon meter districts, the consumption per capita and the night rate for a number of years: —

TABLE NO. 6. — *Cochituate Works.*

YEAR.	Population in Meter Districts.	Before Inspection.		After Inspection.	
		Daily Consumption per Capita.	Night Rate per Capita, One to Four A.M.	Daily Consumption per Capita.	Night Rate per Capita, One to Four A.M.
		Gallons.	*Gallons.*	*Gallons.*	*Gallons.*
1888,	337,000	-	-	45.9	27.4
1889,	337,000	55.3	32.5	48.4	27.1
1890,	356,600	52.1	29.6	47.7	27.0
1891,	360,200	52.1	31.8	53.7	33.2
1892,	337,900	52.8	32.9	53.2	35.0
1893,	379,450	54.5	36.7	54.8	37.9

Mystic Works.

YEAR.	Population in Meter Districts.	Daily Consumption per Capita (Before).	Night Rate per Capita (Before).	Daily Consumption per Capita (After).	Night Rate per Capita (After).
1888,	-	-	-	37.8	22.0
1889,	47,700	47.7	28.7	40.1	23.5
1890,	51,000	43.5	25.2	36.1	21.3
1891,	46,200	45.1	27.3	45.2	29.6
1892,	42,600	39.7	23.8	43.0	27.3
1893,	39,850	44.1	28.2	44.1	28.2

That there is still a consumption at the rate of from 30 to 35 gallons per capita during the hours of the night when little water should be used proves that a large amount of preventable waste still exists. In the Charlestown experiments the night rate was reduced to 15.3 gallons per capita, and in East Boston, during the years 1882 and 1883, even better results were obtained. In the latter district the night rate was reduced to about 12 gallons in a district containing 25,000 inhabitants. This system of waste prevention is in use to a large extent in England, where greater attention has been paid to the question of waste prevention than in the United States.

The records of the Deacon meters do not include the waste due to allowing the water to run for the purpose of preventing the freezing of services, as the meters are not operated during the winter.

The average daily consumption of the Cochituate and Mystic works for the months of November, 1892, and May, 1893, was 51,924,600 gallons, while for the intervening winter months it was 60,149,600 gallons. The difference of 8,225,000 gallons per day, equivalent to 3,380,000 gallons per day or 6 gallons per capita for the entire year, may properly be charged to the cold weather waste. That this cause of waste is not confined to places where the buildings and plumbing are old is shown by the records of consumption in Brookline, where the houses are generally modern and heated throughout. In Brookline the consumption during the month of January, 1893, was 41 per cent. greater than during the previous month of November, while the increase in Boston was 34 per cent.

Measurements taken in Brookline from June to December, 1891, showed that the consumption from midnight to four A.M. was at the rate of 210,000 gallons per day, or 44 per cent. of the total consumption; and after a careful inspection of every fixture the night consumption was still at the rate of 144,000 gallons, or 17.7 gallons per capita. In both Newton and Brookline a large percentage of the taps are metered.

Measurements made on the Mystic works during the week ending Aug. 20, 1893, gave the following rates of consumption for different portions of the twenty-four hours: —

Rate per Head per Day.

Time.	Gallons.
One A.M. to four A.M.	40.8
Four A.M. to seven A.M.	58.6
Seven A.M. to ten A.M.	103.8
Ten A.M. to one P.M.	93.0
One P.M. to four P.M.	98.2
Four P.M. to seven P.M.	79.5
Seven P.M. to ten P.M.	61.9
Ten P.M. to one A.M.	52.9
Average,	73.6

In this case the minimum rate was nearly sixty per cent. of the average and forty per cent. of the maximum. As it is probable that at least 30 gallons of the night rate was wasted, and as we may consider this a uniform rate of waste in the twenty-four hours, the difference between 73.6 and 30, equal to 43.6 gallons, represents quite closely the actual necessary consumption with some allowance for unavoidable leakage. Deducting 15 gallons per capita, which is the quantity used by meter measurement for trade and manufacturing purposes, there remains 28 gallons as the actual requirements for domestic purposes on the Mystic works.

That there exists a waste of from 40 to 50 per cent. of the total consumption in most cities and towns where meters are not generally used is an

accepted fact by those who have studied the question; but it is, I think, the popular idea that this enormous waste can be and is almost entirely prevented by the use of water meters on the services.

The advocates of the use of meters have pointed to the low consumption of those places where meters are used as a proof of this statement; but, while there is no doubt as to the beneficial effect of the use of meters in preventing waste, I do not think that they will accomplish all that is generally claimed. The results obtained in the cities and towns where the largest number of meters are in use show that while the consumption per capita is smaller than in unmetered places of the same general character, still, a very large proportion of the water which the pumping records show is pumped into the mains is not recorded by the service meters.

A very striking proof of this statement is furnished by one of the towns in the metropolitan district. All the water used in the town is measured by a meter on the supply main, and every service pipe is provided with a meter. The works are but four years old, have 18 miles of cast-iron mains, 376 services supplying about 2,300 persons, and, with the exception of water used for flushing mains, street sprinkling, street construction, and for fires, all of the water used is measured by meters on the service pipes. The daily average amount registered by the meter on the supply main in 1893 was 128,560 gallons, while the total recorded by the service meters was 65,180 gallons. Allowing 2,000 gallons per day for blowing off pipes and fires, there remains 61,380 gallons, or nearly 50 per cent. of the total consumption which is unaccounted for.

During the months of May and June, 1894, a careful inspection was made of all the mains and services, resulting in the suppression of leaks, so that during July and August about 90 per cent. of the total quantity recorded by the meter on the supply main was accounted for by the service meters.

In Newton and Fall River, Mass., and Woonsocket, R. I., similar results are shown.

In the city of Newton all services, with the exception of houses having a single faucet, are metered; and yet making a liberal allowance for the amount used by the unmetered takers, the quantity of water delivered into the premises of the water takers during the year 1892 was but little more than one-half of the total quantity pumped. Of a daily average consumption of 1,288,000 gallons, 595,600 gallons were used for public purposes or wasted from the street mains or services, or passed through the meters without being recorded.

In the city of Fall River, during 1892, 2,217,370 gallons per day, equivalent to 27.24 gallons per capita, were pumped into the mains; and 1,274,500 gallons, or 15.66 gallons per capita, were sold; leaving 942,870 gallons, or 11.58 gallons per inhabitant. A small portion of this was used in city buildings and for other public uses; but at least 10 gallons per

capita, or 814,000 gallons per day, more than one-third of the total consumption, cannot be accounted for.

In Woonsocket, R. I., all but a very few of the services are metered, and those few are all provided with self-closing faucets and have no hose connections. The quantities recorded by the meters and the amounts pumped during the year 1893 are as follows: —

	Pumped.	Recorded by Meters.	Percentage.
December 1 to March 1,	46,662,321	21,233,500	45.5
March 1 to June 1,	45,763,500	26,995,684	58.9
June 1 to September 1,	61,589,227	31,943,211	51.8
September 1 to December 1,	50,193,139	26,802,669	53.4
Total for year,	204,208,187	106,975,064	52.4
Estimated quantity used for street watering, fountains, etc.,	–	25,000,000	–
Quantity used by takers paying schedule rates,	–	10,000,000	–
Total,	204,208,187	141,975,064	69.5

In the calculation of the quantity pumped, an allowance of 5 per cent. has been made for the slip of the pumps. Notwithstanding the fact that more than 80 per cent. of the taps are metered, the records show that 62,000,000 gallons per annum, or more than 30 per cent. of the total quantity pumped, is wasted from the mains and services.

These great differences can only be attributed to errors in the quantities registered by the pumps and meters, or to waste and leakage from the street mains and service pipes.

It does not seem probable that the loss due to the slip of the pumps and the loss in registration of the meters is more than 20 per cent. of the quantity registered by the pumps, in which case there seems to be conclusive evidence that the leakage from the mains is an important factor, and that the use of meters will not prevent all waste of water.

Proper Allowance per Capita.

The determination of the quantity to be allowed for domestic use in the metropolitan water supply district depends largely upon whether it be assumed that the use of meters is to be made general, and a more thorough inspection made for waste than has been the rule in past years, or whether the theory that it is cheaper to supply water than to prevent waste is to be carried out in the future as it has been in the past. The records of the cities and towns where the most attention has been given to the prevention

of waste, indicates that at the present time the legitimate demand for domestic use is not more than 30 gallons per capita.

In estimating the quantity to be provided for future years, consideration should be given to the great increase in the number of water fixtures. Table No. 7 gives the number of the different varieties of water fixtures in use on the Sudbury and Cochituate works in 1870, 1880, 1890 and 1892, together with the percentage of increase, as compared with the increase in population and consumption: —

TABLE NO. 7.

Number of Water Fixtures in Use and Fixtures per Capita, etc., on the Cochituate Works, from 1870 to 1892.

NAME OF FIXTURE.	1870.	Per Cent. Increase.	1880.	Per Cent. Increase.	1890.	Per Cent. Increase.	1892.
Taps,	5,893	56.6	9,228	61.7	14,922	12.0	16,706
Sinks,	53,010	59.4	84,498	39.7	118,066	6.0	125,151
Bowls,	23,961	92.5	46,116	39.8	64,462	6.2	68,448
Bath-tubs,	8,892	93.8	17,230	85.2	31,914	17.5	37,495
Water-closets,	25,050	107.7	52,030	75.4	91,280	12.5	102,687
Urinals,	2,447	65.1	4,041	20.7	4,879	−2.6	4,754
Wash tubs,	9,615	99.1	19,139	126.7	43,389	23.0	53,360
Private hydrants	547	−63.9	197	−81.7	36	−50.0	18
Slop hoppers	723	32.2	956	56.2	1,493	−4.1	1,432
Foot baths,	73	90.4	139	101.4	280	−7.1	260
Hydraulic rams,	13	−100.0	-	-	-	-	-
Totals,	130,234	79.3	233,574	58.7	370,721	10.7	410,311
Total population,	250,500	31.7	330,000	24.4	410,600	4.8	430,200
Daily average consumption,	16,257,700	72.2	28,000,000	21.0	33,871,700	22.0	41,312,400
Fixtures per capita,	0.520	36.2	0.708	27.5	0.903	5.6	0.954
Consumption per capita,	64.9	31.0	85.0	−2.9	82.5	16.4	96.0
Consumption per fixture,	124.8	−3.9	119.9	−23.8	91.4	10.5	101.0

The proportion of fixtures per capita was nearly twice as large in 1890 as in 1870. Although it is not to be expected that a person will double the use of water because he has twice as many opportunities of drawing it, yet increased use will surely follow from the increase in the number of fixtures.

Another cause of increased consumption is increased pressure in the mains and services. The constant tendency towards increased height of

buildings creates a continued demand for increased pressure in the supply mains, and with a large pressure there is more lavish use of water and a greater waste by leakage.

Taking into consideration all of the facts of past experience, I am of the opinion that 35 gallons per capita is a liberal allowance for domestic use in the metropolitan district for the next thirty years. For trade and mechanical purposes there is, as before stated, at present a demand for nearly 30 gallons per capita, a large proportion of which is metered, and must, therefore, be considered as legitimate use. The quantity per capita has increased rapidly during the past few years, and it does not appear to me that it will be safe to estimate upon less than 35 gallons per head for these purposes. The present requirements of public use I have estimated as 4 gallons per capita, and for the future increase I have added 1 gallon, making 5 gallons.

We have now considered the three uses of water, and find that for domestic use 35 gallons should be sufficient; that the demand for trade and manufacturing will before many years require at least 35 gallons more, and that 5 gallons are needed for public purposes, or a total of 75 gallons. This quantity represents the amount estimated as required to supply the actual needs of a community similar in character to that within ten miles of Boston, with no allowance for waste; for, although it is probable that a portion of the water sold and paid for by meter measurement is thrown away, it seems to me that in considering the question we must consider water paid for by meter measurement as legitimately used. To this amount of 75 gallons must be added an allowance for waste.

From my knowledge and experience in the operation of the Deacon waste detection system in Boston, and judging from the facts as to the quantity of water pumped which cannot be accounted for in cities and towns using meters, I do not think it possible that the waste can be maintained below 15 gallons per capita; and, if the use of meters or some efficient system of waste prevention is not adopted, the amount wasted will be, as it now is in some of our large cities, from 30 to 60 gallons per inhabitant. The allowance of 15 gallons per inhabitant for leakage and waste is a minimum quantity, and could only be maintained by a thorough meter system and constant inspection.

While I am very firmly of the opinion that stringent measures should be adopted to prevent unnecessary use and waste of water, still, in view of the uncertainties of the accomplishment of the desired results, it seems to me that it will be unsafe to estimate upon less than 25 gallons as an allowance for waste. This added to 75 gallons gives 100 gallons per capita as the quantity which should be used in estimating the requirements of the next thirty years.

Respectfully submitted,

DEXTER BRACKETT.

Appendix No. 3.

IMPROVEMENT OF THE QUALITY OF THE SUDBURY RIVER WATER BY THE DRAINAGE OF THE SWAMPS UPON THE WATER-SHED.

By Desmond FitzGerald.

Boston, Aug. 20, 1894.

Frederic P. Stearns, Esq., *Chief Engineer*, *State Board of Health*.

Dear Sir: — The following report is submitted in answer to your request for a statement as to the improvement that can be expected in the color of Sudbury River water by draining the swamps upon the water-shed, together with the estimated cost of the work.

Studies made during the past four years upon the colors of the waters forming the Boston water supply have assumed important proportions, and have revealed some interesting and valuable facts.

In the seventeenth annual report of the Boston Water Board for the year 1892 it was shown that the color found in surface waters, such as brooks, rivers and upper levels of lakes, is not due to iron, but almost entirely to the presence of organic matter. Observations made upon the Boston water works have proved that the color is a measure of the vegetable matter. Any improvements, therefore, which tend to reduce the color after it has once been taken up, or to prevent it from getting into the water, may be estimated as of value in proportion to the reduction of color.

Large sums were expended upon the Boston storage reservoirs in removing the loam and other organic matter from the sites of the reservoirs. In consequence partly of this outlay it is found that instead of acquiring color during storage, the water, if sufficient time is allowed, actually loses color. During the summer it bleaches to a greater or less degree. We must, therefore, look elsewhere for the source of color.

Careful investigation has shown that the swamps upon the water-sheds are principally responsible. These swamps have been surveyed in many instances, and the colors of the waters determined at various seasons of the year at many places, both where the waters of the inlets come into the

swamps and where the brooks flow out of the swamps. The colors in the storage and distributing reservoirs and at several points in the pipe system in the city have also been recorded at the same time, and in this way a mass of information has been obtained to furnish data for an intelligent study of the most effective way to reduce the color.

Much perplexity has arisen from the inability to measure colors accurately and easily and to represent them by a true scale. A detailed report upon this subject will be found in a report to the Boston Water Board, published in the "Annual Report of the Water Supply Department for the year 1893." It is unnecessary to repeat here what has been so fully set forth in that report. The colors given in the present report have all been reduced to the platinum-cobalt standard, which represents a true scale of color, and one which can be at any time reproduced with accuracy. The colors now observed upon the Boston water works are all taken by means of the colorimeter, described and illustrated in the report referred to, using the platinum standard. For this standard we are indebted to Mr. Allen Hazen, chemist of the State Board of Health; and if its advantages could be appreciated, no other standard would be used. In the nesslerized ammonia or other standards there are errors of intervals in the scale, to say nothing of other sources of error.

Of course the colors here given cannot be compared with those based upon the Nessler scale without a correction, which can, however, be made by means of the following table: —

Table for Converting Nessler Scale to Platinum.

Nessler, .	.10	.20	.30	.40	.50	.60	.70	.80	.90	1.00
Platinum, .	.18	.26	.33	.39	.46	.52	.58	.63	.70	.81
Nessler, .	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00
Platinum, .	.88	.95	1.02	1.09	1.16	1.22	1.29	1.36	1 43	1.50

The average color of Sudbury River water as delivered at Chestnut Hill Reservoir is 0.68; and of the Cochituate, delivered at the same point, 0.27; and the mixture of these two waters after passing through Chestnut Hill Reservoir is delivered into the mains with a color of 0.48. In the centre of the city at Park Square the color is 0.48, and at Mattapan it is 0.44.

The quantity of water delivered to the city of Boston from the Cochituate source is a definite daily amount. As the consumption increases, a greater proportion of water has to be supplied from the highly colored Sudbury, which raises the color of the mixture. While it is probably possible to lower the color of the Cochituate somewhat, it would not be worth while to undertake the task, as this is practically a colorless water. With the Sudbury, however, the case is different, and to this water we will now turn our attention.

Considering the waters of Reservoirs II. and III., which are the lowest reservoirs upon the two branches of the Sudbury, in proportion to their water-sheds, we find that the water is almost exactly the same as that delivered at Chestnut Hill Reservoir; so that, as we should expect, there is no material improvement in color arising from the passage underground through the brick aqueduct sixteen miles in length. The color of the Sudbury at the point of diversion may therefore be placed at 0.70 in round numbers, with the present development; that is to say, this is the average color after passing through the storage reservoirs, with their various fluctuations of level.

If Reservoirs II., III. and IV. did not exist, the color would probably be 0.81, which has been determined by combining the colors of the influents in proportion to their drainage areas. The effect of these reservoirs in reducing the color may be placed at about 14 per cent.

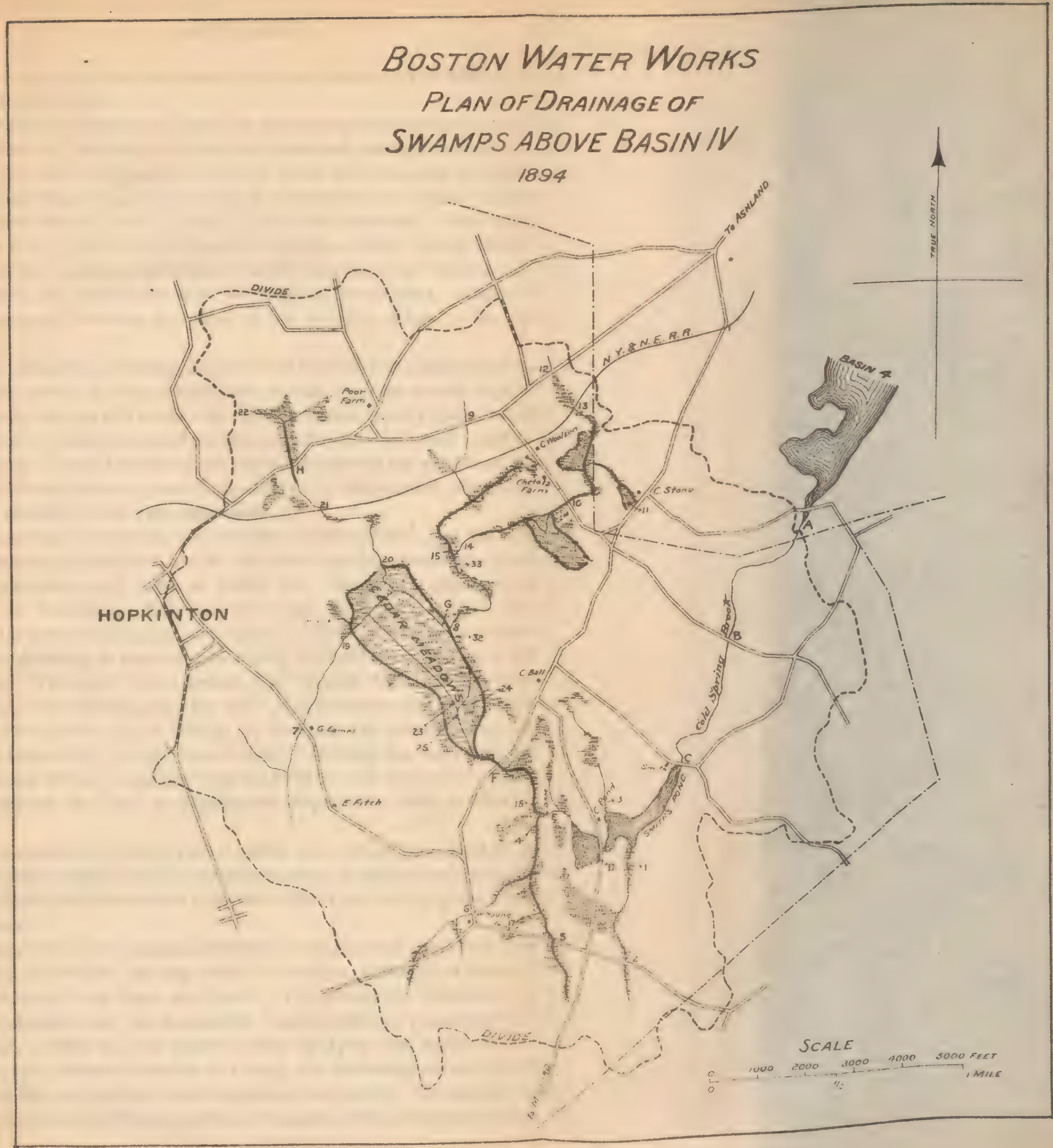
Reservoir IV. (see accompanying plan) covers an area of 167 acres and contains 1,400,000,000 gallons. Its water-shed has an area of 6.43 square miles. The depth of water is about 50 feet at the dam. The daily yield is estimated at 4,900,000 gallons. The water is received almost entirely at the upper end, "A."

The color of the water has here been observed weekly for nearly four years, and from these observations the average of the twelve monthly colors has been found to be 1.04; but, as the amount of water flowing varies very much in the different months, the monthly averages have been multiplied by factors corresponding to the flows, and the summation of these products divided by the factor corresponding to the total flow, which gives 0.94 as the true average color of all the water entering at "A." In order to determine the effect of the reservoir itself in reducing the color of the water, we have to make an allowance for the portion of the water-shed below "A," which has been assumed as supplying water of a color of 0.40. When this figure is combined with 0.94, we have finally 0.88 as the probable color of all the water entering the reservoir, which is filled during the winter and spring months, and is emptied generally during the months of August, September and October. During these months the water at the outlet now averages 0.56 for color. With 0.88 as the color of the water entering the reservoir, and 0.56 as the color at the outlet, we have 36 per cent. reduction in color due to storage.

In Reservoir VI., just completed, it is estimated that a reduction of color will take place in about the same ratio. As Reservoirs IV. and VI. are large compared with the others, and as the organic matter has all been removed from their bottoms and the drainage areas are small, their great value in removing color can be understood.

It is expected that Reservoir V., now building, will reduce Stony Brook from 0.66 where it enters the reservoir to 0.40 at its outlet; and, combining this color with the others in proportion to their water-sheds, the color

PLAN NO. 12



BOSTON WATER WORKS
PLAN OF DRAINAGE OF
SWAMPS ABOVE BASIN IV
1894
TRUE NORTH
To ASHLAND
DIVIDE
N.Y. & N.E. R.R.
BASIN 4
Poor Farm
C. Woolson
Chetola Farm
C. Stone
HOPKINTON
C. Ball
G. Eames
E. Fitch
Cold Spring Brook
Smith's Pond
C. Pond
DIVIDE
SCALE
1000 2000 3000 4000 5000 FEET
1 MILE

of the Sudbury when the new reservoir is completed will probably be about 0.60, instead of 0.70.

Having now considered the effect of the reservoirs in reducing the colors of the waters, it remains to discuss the seasonal changes in color of the brooks. As observations have not been taken with the same frequency or regularity at all points on the brooks, it is necessary to inquire whether an approximate average can be found from a few scattered observations at any given point. Many observations, both upon Cold Spring Brook and elsewhere, have shown that there is a certain regularity of seasonal change in the colors of the brooks upon the Sudbury water-shed. Curves have been constructed, showing the ratios of the monthly colors to the annual mean.

From an inspection of these curves we find that the water attains its highest color in the month of June, that it then rapidly loses color until September, that towards the end of October the color increases rapidly until December, when the curve forms a second maximum, although one lower in color than that of June. After December the color decreases to the middle of March, when the lowest point is reached, as low as in September, after which it increases steadily to the June maximum.

In the spring of the year the swamps are overflowed, and the color is low on account of dilution; but as the yields of the water-sheds diminish, the color increases until June, at which time the pools standing upon the swamps are discharging their last water into the brooks. After this time many of the smaller swamps, particularly at the head waters, yield no flow. The water standing in them may be highly colored, but the effect is not felt until later. The color in the brooks consequently falls until evaporation diminishes in the autumn, and the yield of the streams begins to increase.

When heavy rains occur during the summer, the color of the streams increases temporarily, as has been found by plotting the daily flow of Cold Spring Brook at "A," together with the rainfall and the color. The effect of such storms as those in August and September, 1892, is thus clearly shown.

In the autumn, the freshly fallen leaves and decaying vegetable matter give a slightly different hue to the water, which is rather more greenish than in June, when the color comes from the older peat, which gives a reddish-brown color.

So persistent is this seasonal variation in amount of color that it is distinctly noticed even in the tap water in the city, although of course modified by storage in the large reservoirs. The distinctive character of this cycle of changes may be contrasted with conditions prevailing in Lake Cochituate. There the two maxima occur in April and November. During the winter, when the surface is frozen, the bleaching effects are diminished, and the color of the water increases until April. During this month the ice disappears and the sun and air begin the work of bleaching, and the

color decreases. In November, when the period of stagnation at the bottom ceases, and the highly colored water at the bottom comes to the surface after the great turn-over, we have a second maximum, due partly to the iron in the water at the bottom.

With the assistance of the curves already referred to, the observed colors have been transformed into averages of the twelve monthly colors, and further into the mean color of the total quantity of water flowing, in order to place them upon the same basis as the average 0.94 already found at "A."

Investigations have shown that when planning improvements for the drainage of the swamps, which are the chief sources of color in the water, every swamp must be studied by itself, and that the methods of treatment will differ in detail, although the general principles may remain the same. Two areas of swampy ground have been selected for illustration in this report. The first lies at the head waters of Reservoir IV. in Ashland and Hopkinton, and the second is the largest swamp upon the Sudbury River water-shed, and lies between Rocklawn Mills and Westborough, upon the main line of the Boston & Albany Railroad.

In the first of these cases the method of treatment proposed is by ditches, while in the second these ditches rise to the magnitude of canals of considerable cost, furnished with structures of careful design.

Head Waters of Reservoir IV.

The plan shows in detail the situation of the swamps upon the feeders of Reservoir IV. About a mile above its inlet are two small mill-ponds, and above these ponds is a succession of swamps on the different branches of the brook.

The places where the colors have been observed are designated by the letters and numbers which are seen on the plan and in the first column of the subjoined table of colors. Column 2 gives the areas of the water-sheds above the points designated. The mean colors of the total quantities flowing at these points are given in column 3, and beside them in column 4 are the colors which it is estimated will be found after the contemplated improvements have been made. These are called "future colors." The latter have been obtained by beginning at the upper portions of each feeder, and estimating the effect of each particular local improvement upon the brook at the successive points.

The peculiarities of each case have been studied by an examination of the ground. The depth of the peat, its present effect upon the color of the water and the character of the drainage proposed have entered as factors into the problem. The key to the solution lies in the fact that with the data at hand the present effect of any given piece of swamp can be detected. We have the average color of the various influent waters to compare with

Table of Average Colors of All the Water flowing at Various Points upon the Branches of Cold Spring Brook, feeding Reservoir IV.

Column 1. Location on Plan.	Column 2. Areas in Million Square Feet.	Column 3. Present Colors.	Column 4. Future Colors.
A, ...	152.7	.94	.70
B, ...	–	1.00	.73
C, ...	122.5	1.04	.75
D, ...	105.4	1.17	.84
E, ...	–	1.03	.70
F, ...	83.3	1.37	.73
G, ...	–	1.44	–
H, ...	9.4	.55	.40
No. 1, ...	10.7	1.09	1.09
2, ...	2.8	.85	.85
4, ...	17.4	.57	.48
5, ...	2.5	1.00	.50
6, ...	5.7	.47	.47
7, ...	–	.32	.32
8, ...	28.5	1.14	.77
9, ...	–	.57	.57
10, ...	6.9	1.16	.54
11, ...	–	.52	.30
12, ...	–	.52	.52
13, ...	1.9	.44	.44
14, ...	11.4	1.39	.72
15, ...	14.6	.37	.25
18, ...	85.5	1.40	.74
19, ...	10.4	.27	.27
21, ...	10.3	.62	.48
32, ...	–	1.33	–
33, ...	26.0	.48	.46

the effluent. The difference is evidently the effect of the swamp. If all the influent water is carried through or around the swamp in channels of sufficient capacity and at a proper grade to prevent contact with the swamp, it is evident that the effect of the swamp will be very much reduced, although it has not been found practicable to plan the channels in such a manner as wholly to eliminate the effect of the swamps. The ditches which are proposed are shown by heavy lines on the plan. When the swamp is long and narrow, as above No. 15 and No. 4, it has been decided to dig a single deep channel through the middle; where the swamp lies in a more rounded form, as between No. 14 and No. 10, intercepting channels have been planned around the swamp. One of these channels will generally be larger than the other, to take the influent water from the larger portion of the water-shed; and the other channels will be more in the nature of surface ditches discharging into the former.

To render the method of procedure clearer, the following example has been selected from this group of swamps, and the calculations are given in full. It is desired to know what is the present effect of Cedar Meadows above No. 8, and what the future effect will be when drained.

Present Conditions.

	Areas in Millions of Square Feet.		Colors.		Product, Expressive of Coloring Matter.
No. 8,	28.5	×	1.14	=	32.49
19,	10.4	×	0.27	=	2.85
21,	10.3	×	0.62	=	6.39
Upland,	27.1	×	0.38	=	10.30
Totals,	76.3	×	0.68	=	52.03
Cedar Meadows,	7.0	×	8.87	=	62.09
Grand totals,	83.3	×	1.37	=	114.12

In the above table the colors of the first three numbers are from observations. The color 0.38 for the upland adjoining Cedar Meadows is deduced from other considerations. These four items make up the influents feeding the meadows. The grand total product 114.12 is from observations at F, the outlet of the meadows, where the average color is 1.37 and the area 83,300,000 square feet. It is obvious that the difference between 114.12 and 52.03 must represent the product value of the meadows, viz., 62.09, which, divided by their area, 7,000,000 square feet, gives 8.87 as the color now attributed to Cedar Meadows.

Future Conditions.

	Areas in Millions of Square Feet.		Colors.		Product, Expressive of Coloring Matter.
No. 8,	28.5	×	0.77	=	21.93
19,	10.4	×	0.27	=	2.85
21,	10.3	×	0.48	=	4.98
Upland,	27.1	×	0.38	=	10.30
Totals,	76.3	×	0.52	=	40.06
Cedar Meadows,	7.0	×	3.00	=	21.00
Grand totals,	83.3	×	0.73	=	61.06

$61.06 \div 83.3 = 0.73$, the new estimated color at the outlet F.

It will be noticed that in the foregoing calculations the future average colors of the influents entering Cedar Meadows will be 0.52, deduced from proposed local improvements upon these feeders; and that the present color of this water, taken from the first table, is 0.68, and that the color attributed to the Cedar Meadows area of 7,000,000 square feet is reduced

from 8.87 to 3.00. This latter is an assumption made upon consideration of the fact that the water will be carried rapidly in the new channels, and that the character of Cedar Meadows will be changed to hard land by the lowering of its water table.

The depth of peat in Cedar Meadows is about 2.5 feet on the average, and by digging holes at a number of places it has been found that the colors of the water standing in the peat vary from 5.00 to 14.00. The peat is underlaid by white sand, in which the water is practically colorless, if reliance can be placed on the results of a test well.

By the successive applications of the same method in a direction towards the mouth of the stream at "A," we estimate that the future mean color at this point will be 0.70 instead of 0.94, the present mean.

It now remains to ascertain the effect of Reservoir IV. itself upon these colors. It is estimated that the future color 0.70 will be reduced about 36 per cent., which is the same proportion as the present reduction already discussed, and that the future color at the outlet when the water is drawn off will be 0.45. This, then, is the final reduction of color which it is estimated will result from carrying out the drainage of the swamps upon the head waters of Reservoir IV., as suggested. It remains to give a brief description of the work, with the estimate of cost. Fortunately, there is ample fall to carry out the improvements at moderate expense.

Starting at the head waters and working down stream, we have at No. 11 two small ditches of 10 square feet cross-section, with a combined length of 1,800 feet, 2 feet deep, slopes two to one, and 1 foot wide on the bottom. These will unite in a stream which will discharge into a channel to be cut along the easterly margin of the swamp below No. 13. For a length of 1,000 feet this channel will be 4 feet deep, with a cross-section of 24 square feet. For the next 1,000 feet, coming down to No. 10, the water will flow very nearly in the present channel. Above No. 10 and below the railroad crossing (No. 13) there will be an intercepting ditch along the westerly margin of the swamp, 2,200 feet long and 3 feet deep. The culvert in the road at No. 10 is to be lowered 2.5 feet, to grade 275.50. Below No. 10 the main channel will extend 1,700 feet in length, 3 feet wide at bottom and 3.5 feet deep. The intercepting ditches just below No. 10 will be 3,000 feet in length, with 12 square feet cross-section. The improvement on the branch of the brook above No. 15, extending north-easterly to the fine springs on Chetola farm, consists in a main channel of 20 square feet cross-section, 3,000 feet in length. At H the culvert is lowered 1.5 feet, to grade 314.50, and the stream lowered a short distance below the culvert.

This brings us to Cedar Meadows, through which there are to be two main channels, one on each side; that on the north side will be 2,200 feet long as far as No. 8, 4.5 deep and 2 feet wide at bottom. The remaining portion below No. 8 to F will be 3,100 feet long, 7 feet wide at bottom and 4.5 feet deep. The southerly channel is to be 4,200 feet long, 5 feet wide

and 4 feet deep. The culvert at F is to be lowered 3 feet, to grade 260. A small intercepting ditch is proposed at the north-west end of Cedar Meadows, about 1,600 feet long and 3 feet deep.

From F to E the main channel will be 1,700 feet long, 10 feet wide on bottom, with an average depth of 4.5 feet. On the branch of the brook above No. 4 we shall have, above No. 5, a ditch of 10 square feet area, 600 feet long. The culvert at No. 5 is to be lowered 2.5 feet, to grade 263.5. Below No. 5 there will be a channel following nearly the present brook, 1,600 feet long and with an additional cross-section of 8 square feet. Above the junction of the brook flowing from No. 6 there will be a ditch 700 feet long, of 10 square feet sectional area, and below this junction a channel 1,100 feet long, of 12 square feet additional section.

The channels have been designed to carry three-quarters of an inch of rainfall collected in twenty-four hours, with a velocity of about 2 feet per second.

In the main channels in Cedar Meadows this amount of water will give a depth of about 2 feet, leaving the surface still 2.5 feet below the present surface of the swamp. It is expected that the surface of the swamp will be lowered about 0.75 feet from shrinkage after the improvements are carried out.

The cost of carrying out all this work should be about $12,000, which is about $44 per acre of swamp, or $8.57 per million gallons of storage capacity in Reservoir IV., or about $2,000 per million gallons of available daily yield.

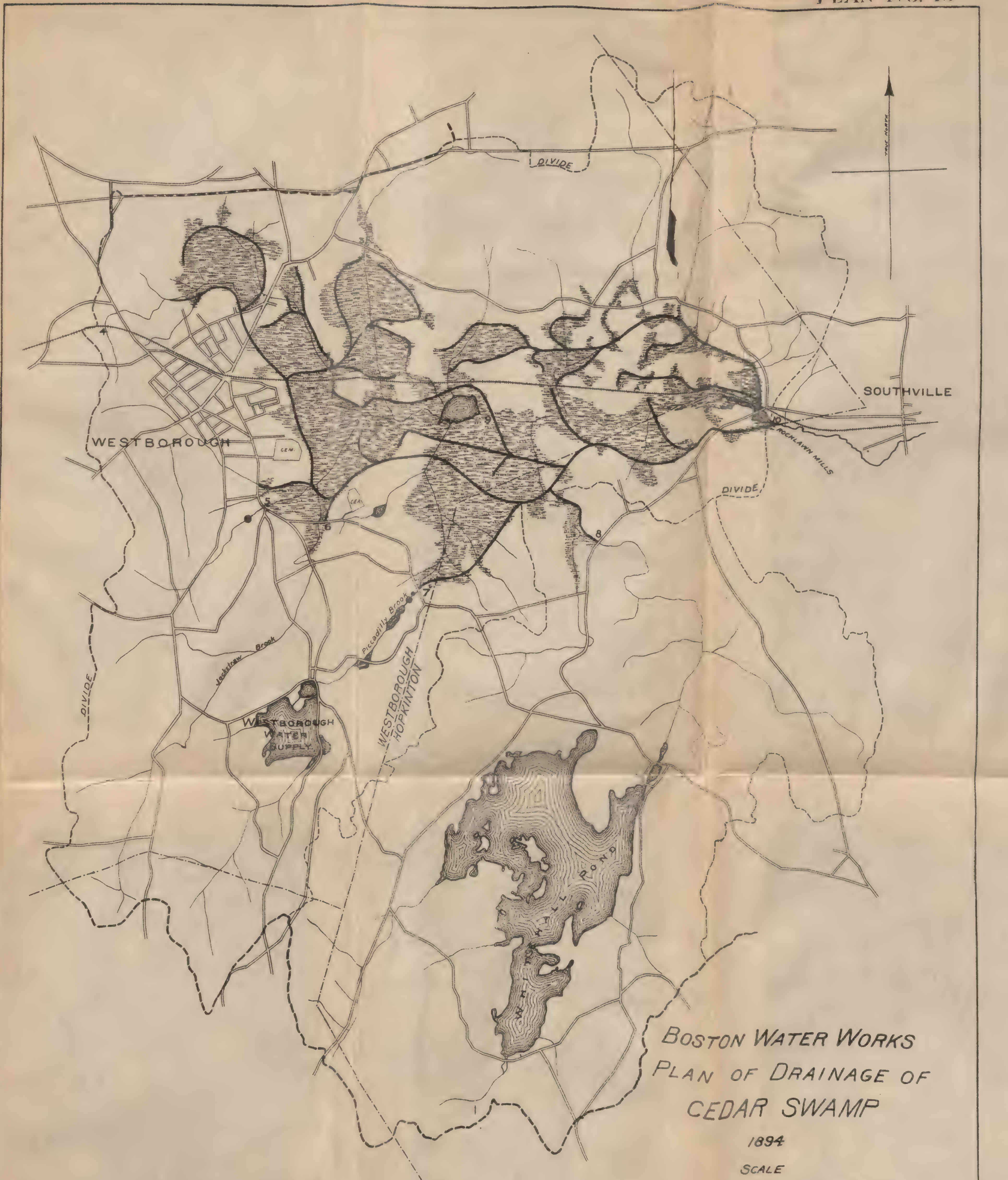
Cedar Swamp.

The second area adopted for illustration embraces Cedar Swamp, at the head waters of Sudbury River in Westborough. The outlet of the swamp is controlled by a dam at Rocklawn Mills, now owned by the city of Boston. The water-shed above this point is 20.2 square miles, of which in round numbers 3 are included in the swamp.

The Boston & Albany Railroad divides this swamp lengthwise into two portions, the larger of which lies upon the southerly side of the railway and has a water-shed of 14.8 square miles. The portions of the swamp on the northerly side, with a water-shed of 5.4 square miles, are broken into irregular masses by the topography of the country, making the studies for drainage schemes exceedingly complicated. There are three large brooks entering the swamp from the south and a number of smaller ones from the north. An accompanying plan shows this territory. A sufficient number of soundings and borings have been put down to give an accurate idea of the materials to be encountered in building the canals.

To the eastward of Cedar Swamp Pond the mud or peat is on an average about 4 feet in depth, but from the pond westerly the peaty deposits rapidly deepen over quite a large area, attaining a depth of 40 feet in some places.

PLAN No. 13


BOSTON WATER WORKS
PLAN OF DRAINAGE OF
CEDAR SWAMP
1894
SCALE
0 1000 2000 3000 4000 5000 FEET
0 1/2 1 MILE
TRUE NORTH
DIVIDE
DIVIDE
DIVIDE
WESTBOROUGH
SOUTHVILLE
ROCKLAWN MILLS
CEM.
CEM.
Piccadilly Brook
Jackstraw Brook
WESTBOROUGH WATER SUPPLY
WESTBOROUGH
HOPKINTON
WHITEHALL POND
4
5
6
7
8
9
10

There are also some deep pockets of mud in the detached portions of the swamp north of the railway. The shallower portions of the swamp at the lower end are underlaid by a fine white sand, and quicksand is found in pockets upon portions of the territory.

For the purpose of studying the colors of the waters, ten stations were selected, eight of these being at the inlets of the brooks into the swamp. No. 9 is just below Cedar Swamp Pond, and No. 10 at Rocklawn Mills.

The following table shows the areas of the separate portions of the water-sheds above the points selected: —

Table of Areas.

	Square Miles.
No. 1, Small brook, north side,	.64
2, Small brook, north side,	.56
3, Small brook, north side,	.52
4, Small brook, north side,	.06
5, Denny Brook, south side,	.37
6, Jackstraw Brook, south side,	1.64
7, Piccadilly Brook, south side,	1.78
8, Whitehall Brook, south side,	6.93
Upland below these points on the brooks,	4.70
9, Swamp,	3.00
10, Total, Rocklawn Mills,	20.20

The estimate of the present colors due to Cedar Swamp is based upon the observations recorded in the following table: —

Table of Colors at Ten Points, Cedar Swamp.

DATE.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.	No. 9.	No. 10.
May 14, 1892,	.58	.29	.22	.36	.24	.70	.24	.81	1.29	1.16
June 2, 1892,	.66	.31	.29	1.16	.30	.35	.24	.88	1.85	1.65
July 12, 1892,	.58	.22	–	–	.26	.15	.22	.75	.81	.81
Aug. 4, 1892,	.63	.32	.47	.61	.49	.09	.32	.62	.61	.88
Sept. 22, 1892,	.41	.13	.15	–	.29	.11	.18	.66	1.75	1.32
Dec. 12, 1892,	.45	.09	.20	.49	.21	.40	.20	.75	1.22	1.29
June 4, 1894,	.56	.20	.30	.87	.33	.40	.33	.80	2.80	2.40
Sum,	3.87	1.56	1.63	3.49	2.12	2.20	1.73	5.27	10.33	9.51
Mean,	.55	.22	.27	.70	.30	.31	.25	.75	1.48	1.36

The first eight columns in the above table represent the colors in the brooks entering the swamp. No. 9 is in the swamp and No. 10 is at the outlet.

The mean color of the effluent No. 10, as thus observed, 1.36, has been reduced 13 per cent. to bring it to the average of the twelve monthly colors found by comparison with the seasonal curves already referred to, which gives 1.18. This color has been reduced 10 per cent., to 1.06, the average color of the total quantity of water flowing at No. 10.

The mean of the observed colors of the eight influents with their varying drainage areas is 0.52, which, when similarly reduced for the twelve months and for the fluctuating flow, gives 0.36 as the mean color for the total quantity of influent water from 12.5 square miles of water-shed.

If the 4.7 square miles of upland adjoining the swamp be debited with the same color, we shall have 17.2 square miles x 0.36 = 6.192. The effluent No. 10 = 20.2 x 1.06 = 21.412. If from 21.412 we subtract 6.192, we shall have 15.22 as the product for the swamp, which, divided by 3 square miles, gives 5.07 as the present color attributed to the swamp itself. It is estimated that this will be reduced to 2.0 by the construction of the proposed channels. If, now, we add 3 x 2 = 6.00 to 6.192, the product for the influents, we have 12.192; and if this be divided by 20.2, we have 0.60 for the color of the water at No. 10 after the canals have been built; that is to say, it is estimated that the average color of the water will be improved from 1.06 to 0.60, or 43 per cent.

Description of Canals.

The scheme of works by which it is hoped to secure this reduction in color and organic matter in the water may be briefly described as follows: —

Two main intercepting canals are projected, skirting the sides of the swamp upon the northerly and southerly sides of the railway, as shown on the plan. The southerly canal is to be very much the larger. It will drain 14.8 square miles on the south and also 2.5 square miles of the Westborough end of the swamp lying to the north of the railway, making 17.3 square miles. This leaves 2.9 square miles for the northerly canal, which is in consequence comparatively inexpensive. The latter is to be carried across the railway below Rocklawn Mills, and will there discharge into the river near the outlet of the southerly canal.

The general plan upon which these canals have been designed is as follows: —

Their capacity has been fixed to discharge 0.75 inches of rainfall collected in twenty-four hours on their respective water-sheds, the depth to be such that the ordinary flow leaves the water line in the canal about 6 feet below the present level of the swamp; the velocity in the canals at all times, even when running full, to be limited to 1.5 feet per second; they must

also be constructed to overflow safely at several points along their course, in times of extraordinary freshets.

In the lower portions of the southerly canal the top width will be 38.22 feet. It will be 10 feet deep and 8.22 feet wide on the bottom, with slopes of 1.5 to 1. The sides and bottom will be of gravel. It is to be built just beyond the edge of the hard land, and, for purposes of economy, within the swamp. The channel has been located so as to avoid quicksand. As far as possible, a good bottom has been selected.

As the outlet is to be a free discharge, even in times of high back water in the river, it is necessary to provide some method for using up the head. The canal will pass under a highway at Rocklawn Mills, and at this point the water will pass through a culvert 112 feet long, of 30 square feet sectional area. A heavily protected channel will extend a short distance below the culvert, and will be provided with a massive triangular notch at its outlet, below which the water will tumble over a mass of boulders into the river. By means of the notch the head will be held up in the culvert and the velocity regulated in the canal.

The total cost of the works has been estimated at $250,000, a large sum, but this expenditure it is believed is justified by the great benefits to be realized. This makes a cost of about $125 per acre of swamp. Owing to the magnitude of the work and the various difficulties attending its execution, a special act was procured from the Legislature in 1892 to facilitate the carrying out of the plan.

If all the swamps existing upon the Sudbury River water-shed are improved upon the same general lines here laid down, it is estimated finally that when taken in connection with the effect of the storage, the color of Sudbury River water delivered at Chestnut Hill Reservoir may be reduced to 0.37.

The estimated cost of carrying out all the drainage schemes is $350,000.

In conclusion, I desire to add that the estimated improvements in the color of the water have been made upon a conservative basis; but, even if the improvements in the color of the water are found to be no greater than here estimated, it will, I believe, be impossible to produce the same effect by an equal expenditure of money in any other way now known to science.

Very truly yours,

DESMOND FITZGERALD.

Appendix No. 4.

ON THE AMOUNT AND CHARACTER OF ORGANIC MATTER IN SOILS AND ITS BEARING ON THE STORAGE OF WATER IN RESERVOIRS.*

By Thomas M. Drown, M.D., Chemist of the Board.

Many statements have been made in previous reports of the Board, concerning the injurious effect on impounded water of the organic matter in the bottoms and sides of reservoirs, and great stress has been laid on the importance of removing all vegetation, as well as the upper layers of the soil, before filling a new basin with water.†

In order to determine in any case just how far it is necessary to go in the removal of the surface soil, a knowledge of the composition of the soil, based on chemical analysis, is a much surer guide than the unaided eye. It is not merely a question of the effective cleaning of the bottom and sides of the reservoir, but also of avoiding the expense involved in stripping the soil to a greater depth than is necessary. In connection with the investigations of the State Board of Health, relative to a water supply for the city of Boston and its suburbs, surveys have been made for an immense storage reservoir on the south branch of the Nashua River above Clinton, and it was thought desirable that a thorough knowledge of the character of the soil should be obtained as a basis for determining the amount which it would be necessary to remove to obtain a clean bottom and sides practically free from organic matter. Samples of soils, representing sections of the ground to a depth of three feet, were taken at nine places in Clinton, Sterling, West Boylston, and Boylston, and in one case at the bottom of a mill pond.

* Reprinted from the 25th annual report of the Mass. State Board of Health for 1893.

† Compare special report of the State Board of Health upon the Examination of Water Supplies, 1890, pages 748, 772, 773; annual report of State Board of Health for 1891, page 381.

Each of these nine sections were divided into six or seven samples for analysis, the upper portion being divided into thin layers of two to three inches, the lower portions, with less organic matter, into layers of six inches to one foot in depth.

The amount of organic matter in these samples was determined (after careful drying to a constant weight at 100° C.) by heating the samples to a bright red heat. The loss on ignition thus obtained represents approximately the organic matter in the samples. But in order to get a better knowledge of the character of this organic matter, the amounts of carbon and of nitrogen were also determined in each sample,— the former by combustion in oxygen, the latter by the Kjeldahl method. In series 9 and 10, the amount of hydrogen was also determined.*

Owing to the heterogeneous character of many of the samples, composed often of a mixture of soil, roots and large stones, it is sometimes extremely difficult to get a sample for analysis that shall fairly represent the layer in question. Perhaps some of the apparent irregularities in the results may be due to this cause. But though this difficulty is inherent in the investigation, it is not believed to seriously affect the results, or the conclusions drawn from them.

The results obtained in the analyses of the nine sections of soil, and the deposit from the bottom of the mill pond, are given in the accompanying tables. The largest amount of organic matter found was from a swamp at the head of Boylston Mill Pond (Series 7), and the next largest in amount from the hillside near the site of the proposed dam (Series 4). The other series, from very dissimilar ground, did not differ very widely in the amount of organic matter present, although they included both unwooded and uncultivated land and wooded and manured pasture land. But in all the series there is usually a rapid falling off in the amount of the organic matter below a depth of nine to eleven inches. At the depth of three feet the amount of organic matter, as shown by the loss on ignition, in no case reaches two per cent., and in the majority of the cases it is below one per cent. The mud taken from the bottom of the Mill Pond at different points contained very variable amounts of organic matter, from almost nothing at one place in the shallow portion to nearly 15 per cent. in the deeper portion.

It was thought that the relation of the amount of nitrogen to the amount of carbon in the organic matter might throw some light on its character and its likelihood to undergo decomposition. This relation is given to the column headed $\frac{C}{N}$. The only series in which the nitrogen ratio is noticeably higher than the rest is No. 5, from low pasture land. Series Nos. 4 and 6, both from hillsides, show a noticeably high carbon ratio, and the others are not very dissimilar in their proportion of carbon to nitrogen.

* All the analyses in this investigation were made by Miss Elizabeth Mason.

An attempt was made to imitate the conditions which would obtain if the reservoir should be filled with water without removing the soil, in order to determine what would be the effect of each of the soils examined on water in contact with it. It is obvious that no laboratory experiment could exactly reproduce the conditions which would exist in a reservoir. Thus it would not be easy to imitate the period of long stagnation of the water during the summer, when the deeper layers of the water are in contact with the soil without an opportunity to get a fresh supply of oxygen from the air. Still it was thought that some idea of the effect of the different soils on the water could be obtained by treating the samples with water for a definite time, and then examining the solutions thus obtained with respect to the character of the organic matter dissolved. In order to hasten the action of the water on the soils, it was heated to 65° C., and the time of contact at this temperature was six hours. The waters were then filtered and the filtrate examined by the usual methods used in the sanitary analysis of water. After standing one week the waters were again tested for free ammonia, to ascertain the amount of decomposition which had gone on in this time, thus obtaining information as to the character of the organic matter dissolved. The *actual amounts* of organic matter found in these solutions, as indicated by the albuminoid ammonia and oxygen consumed, are not especially significant, since they would probably have been very different if another temperature or a greater or less time of treatment had been adopted. But a comparison of the amounts dissolved from the soils in each series, and a comparison of the series with each other, yield information as to the relative facility with which each of the samples examined gives up organic matter to water with which it comes in contact.

In the various experiments tried the proportion of soil to water differed, and in some cases distilled water was used and in others Cochituate water. But in the tables the results of series 1 to 8 have been calculated to represent the effect of the treatment of 100 grams of soil with two litres of pure water at 65° C. for six hours. In series 9 and 10 no heat was employed. In these experiments 250 grams of each sample were placed in a bottle with two litres of pure distilled water. After one week, one litre of this water was filtered off and analyzed, and at the end of the second week the remaining water was examined.

In comparing these tables of analyses of the waters with the corresponding tables giving the percentage determinations of loss on ignition, carbon and nitrogen, a general agreement will be noticed; that is to say, the samples containing the most organic matter give, as a rule, the most concentrated solutions of organic matter. But the analyses do not indicate more than a very general correspondence of this kind. It will also be noted that the amount of decomposition going on in these solutions, indicated by the increase of free ammonia on standing one week, is, in general, also

proportional to the amount of organic matter present. The most notable increase in the free ammonia is generally in the solutions prepared from the surface samples. In solutions from the deeper samples there is generally a decrease of free ammonia indicating doubtless its oxidation to nitrates. The samples from the bottom of the Mill Pond (series 8) give solutions which have little or no tendency to develop free ammonia. This might be expected from the fact that the organic matter they contain has long been in contact with water.

The effect of the soil on the color of water is given both for colorless distilled water, and for Cochituate water having an original color of about 0.55 on the scale used in the analyses of the State Board of Health. In these color determinations the water was not heated, and the length of time of contact with the soil was about 18 hours. It will be noticed that in some cases the deeper samples actually diminished the color of the Cochituate water.

As a preliminary conclusion, based on the facts determined in this investigation, it may be said that the effect of the organic matter in these various soils on the water in contact with them is simply a question of its amount, and that its origin and composition seem to be without marked influence. The watershed from which the samples were taken is very sparsely populated, and the organic matter in all cases is mainly of vegetable origin.

It is probable, therefore, that we need only concern ourselves with the amount of organic matter in a soil of this character in determining the necessity of its removal, and as a provisional standard we may perhaps fix 1.5 to 2 per cent. of organic matter, as determined by the loss on ignition of the sample dried at 100° C., as the permissible limit of organic matter that may be allowed to remain on the bottom and sides of a reservoir.

SERIES 1.

From a Cornfield One-quarter Mile below Clarendon Mills, West Boylston. Cultivated Fertilized Ground in Bottoms. Samples taken from Surface to Three Feet below Surface. All Samples dried at 100° C.

	Loss on Ignition. (Per Cent.)	Carbon. (Per Cent.)	Nitrogen. (Per Cent.)	Ratio. $\frac{c}{n}$
1*a*. Surface to 2 in. below, ...	8.54	5.12	0.47	10.9
1*b*. 2 in. to 4 in. below surface, . . .	6.83	3.55	0.21	16.9
1*c*. 4 in. to 6 in. below surface, . . .	7.43	3.47	0.30	11.5
1*d*. 6 in. to 9 in. below surface, . . .	4.27	2.03	0.21	9.7
1*e*. 9 in. to 14 in. below surface, . . .	1.37	0.26	0.04	6.5
1*f*. 14 in. to 20 in. below surface, . . .	1.07	0.16	0.02	8.0
1*g*. 3 feet below surface, ...	0.78	0.15	0.05	3.0

Sanitary Analysis of Water with which the Soils had been treated as described.

[Parts per 100,000.]

	Free Ammonia.	Free Ammonia after Standing One Week.	Albuminoid Ammonia.	Oxygen Consumed.	Color with Distilled Water.	Effect of Soils on Color of Cochituate Water of Color 0.55.
1*a*. Surface to 2 in. below, . .	0.0343	0.1107	0.1914	2.2368	Not det'd.	Not det'd.
1*b*. 2 in. to 4 in. below surface, .	0.0424	0.0984	0.1437	2.0837	"	"
1*c*. 4 in. to 6 in. below surface, .	0.0317	0.0913	0.1538	2.5290	"	"
1*d*. 6 in. to 9 in. below surface, .	0.0317	0.0359	0.0881	0.9733	"	"
1*e*. 9 in. to 14 in. below surface, .	0.0212	0.0076	0.0351	0.4947	"	"
1*f*. 14 in. to 20 in. below surface, .	0.0194	0.0076	0.0189	0.2515	"	"
1*g*. 3 feet below surface, . . .	0.0229	0.0374	0.0105	0.2763	"	"

Series 2.

From a very Steep Slope One-quarter Mile below Clarendon Mills, West Boylston. Not wooded or cultivated. Samples taken from Surface to Three Feet below Surface. All Samples dried at 100° C.

	Loss on Ignition. (Per Cent.)	Carbon. (Per Cent.)	Nitrogen. (Per Cent.)	Ratio. $\frac{c}{n}$
2a. Surface to 2 in. below, ...	4.55	2.26	0.14	16.1
2b. 2 in. to 4 in. below surface, . . .	10.19	5.00	0.27	18.5
2c. 4 in. to 7 in. below surface, . . .	7.62	2.52	0.36	7.0
2d. 7 in. to 10 in. below surface, . . .	7.70	2.93	0.21	14.0
2e. 10 in. to 16 in. below surface, . . .	1.01	0.18	0.05	3.6
2f. 16 in. to 22 in. below surface, . . .	1.63	0.24	0.13	1.8
2g. 3 feet below surface, ...	0.80	0.23	0.03	7.7

Sanitary analysis of water with which the Soils had been treated as described.

[Parts per 100,000.]

	Free Ammonia.	Free Ammonia after Standing One Week.	Albuminoid Ammonia.	Oxygen Consumed.	Color with Distilled Water.	Effect of Soils on Color of Cochituate Water of Color 0.55.
2a. Surface to 2 in. below, . .	0.0340	0.0669	0.0852	1.4732	0.40	0.90
2b. 2 in. to 4 in. below surface, .	0.0227	0.1215	0.1372	2.3334	0.48	1.00
2c. 4 in. to 7 in. below surface, .	0.0227	0.0335	0.1261	2.3092	0.35	0.85
2d. 7 in. to 10 in. below surface, .	0.0178	0.0062	0.1349	2.6945	0.52	0.85
2e. 10 in. to 16 in. below surface, .	0.0307	0.0130	0.0205	0.5428	0.15	0.70
2f. 16 in. to 22 in. below surface, .	0.0190	0.0000	0.0196	0.4560	–	–
2g. 3 feet below surface, . . .	0.0323	0.0213	0.0267	0.3756	0.00	0.45

Series 3.

From Pasture Land One Mile North of South Clinton Station. Sandy and Gravelly and Nearly Level. Samples taken from Surface to Three Feet below Surface. All Samples dried at 100° C.

	Loss on Ignition. (Per Cent.)	Carbon. (Per Cent.)	Nitrogen. (Per Cent.)	Ratio. $\frac{c}{n}$
3*a*. Surface to 2 in. below, ...	7.85	3.51	0.27	13.0
3*b*. 2 in. to 4 in. below surface, . . .	5.85	2.18	0.24	9.1
3*c*. 4 in. to 6 in. below surface, . . .	4.93	2.28	0.20	11.4
3*d*. 6 in. to 11 in. below surface, . . .	1.73	0.50	0.03	16.7
3*e*. 11 in. to 16 in. below surface, . . .	1.43	0.13	0.04	3.3
3*f*. 16 in. to 36 in. below surface, . . .	0.81	0.02	0.02	1.0

Sanitary Analysis of Water with which the Soils had been treated as described.

[Parts per 100,000.]

	Free Ammonia.	Free Ammonia after Standing One Week.	Albuminoid Ammonia.	Oxygen Consumed.	Color with Distilled Water.	Effect of Soils on Color of Cochituate Water of Color 0.55.
3*a*. Surface to 2 in. below, . .	0.0341	0.0541	0.1540	1.4423	0.30	0.60
3*b*. 2 to 4 in. below surface, . .	0.0457	0.0693	0.1041	1.4855	0.22	0.65
3*c*. 4 in. to 6 in. below surface, .	0.0857	0.0745	0.0888	1.2000	0.15	0.60
3*d*. 6 in. to 11 in. below surface, .	0.0427	0.0138	0.0321	0.4361	0.12	0.50
3*e*. 11 in. to 16 in. below surface, .	0.0400	0.0290	0.0125	0.1689	0.00	0.13
3*f*. 16 in to 36 in. below surface, .	0.0214	0.0121	0.0067	0.1000	0.00	0.33

SERIES 4.

From a very Steep, Clayey Hillside near Site of Proposed Dam. Samples taken from Surface to 3 feet below surface. All Samples dried at 100° C.

	Loss on Ignition. (Per Cent.)	Carbon. (Per Cent.)	Nitrogen. (Per Cent.)	Ratio. $\frac{c}{n}$
4a. Surface to 2 in. below, ...	17.79	8.19	0.56	14.6
4b. 2 in. to 4 in. below surface, . . .	11.04	5.85	0.38	15.4
4c. 4 in. to 6 in. below surface, . . .	8.55	4.31	0.12	35.9
4d. 6 in. to 11 in. below surface, . . .	4.04	1.26	0.05	25.2
4e. 11 in. to 16 in. below surface, . . .	2.80	0.47	0.03	15.7
4f. 3 feet below surface, ...	1.76	0.10	0.01	10.0

Sanitary Analysis of Water with which the Soils had been treated as described.

[Parts per 100,000].

	Free Ammonia.	Free Ammonia after Standing One Week.	Albuminoid Ammonia.	Oxygen Consumed.	Color with Distilled Water.	Effect of Soils on Color of Cochituate Water of Color 0.55.
4a. Surface to 2 in. below, . .	0.0622	0.3555	0.4240	7.7333	0.30	0.75
4b. 2 in. to 4 in. below surface, .	0.2581	0.4749	0.8032	8.0323	0.30	0.75
4c. 4 in. to 6 in. below surface, .	0.0454	0.1513	0.1968	4.2622	0.48	0.80
4d. 6 in. to 11 in. below sutface, .	0.0071	0.0267	0.0542	1.0422	0.32	0.55
4e. 11 in. to 16 in. below surface, .	0.0077	0.0154	0.0369	0.5427	0.12	0.55
4f. 3 feet below surface, . . .	0.0138	0.0092	0.0155	0.3000	0.40	0.70

SERIES 5.

From Level Pasture Land near River, Half a Mile East of Boylston Station. Silt Formation. Samples taken from Surface to Three Feet Six Inches below Surface. All Samples dried at 100° C.

	Loss on Ignition. (Per Cent.)	Carbon. (Per Cent.)	Nitrogen. (Per Cent.)	Ratio. $\frac{c}{n}$
5*a*. Surface to 2 in. below, ...	9.40	4.19	0.43	9.7
5*b*. 2 in. to 4 in. below surface, . . .	3.94	1.33	0.15	8.9
5*c*. 4 in. to 7 in. below surface, . . .	3.04	1.02	0.11	9.3
5*d*. 7 in. to 10 in. below surface, . . .	2.12	0.63	0.10	6.3
5*e*. 10 in. to 15 in. below surface, . . .	2.51	0.73	0.09	8.1
5*f*. 15 in. to 20 in. below surface, . . .	0.88	0.16	0.03	5.3
5*g*. 3 ft. 6 in. below surface, ...	1.09	0.21	0.02	10.5

Sanitary Analysis of Water with which the Soils had been treated as described.

[Parts per 100,000.]

	Free Ammonia.	Free Ammonia after Standing One Week.	Albuminoid Ammonia.	Oxygen Consumed.	Color with Distilled Water.	Effect of Soils on Color of Cochituate Water of Color 0.55.
5*a*. Surface to 2 in. below, . .	0.0349	0.2573	0.5556	2.7619	0.20	0.70
5*b*. 2 in. to 4 in. below surface, .	0.0533	0.0195	0.0636	1.5876	0.20	0.65
5*c*. 4 in. to 7 in. below surface, .	0.0380	0.0099	0.0670	0.8444	0.20	0.70
5*d*. 7 in. to 10 in. below surface, .	0.0166	0.0325	0.0316	0.2882	0.20	0.60
5*e*. 10 in. to 15 in. below surface, .	0.0182	0.0117	0.0519	0.6127	0.25	0.70
5*f*. 15 in. to 20 in. below surface, .	0.0188	0.0041	0.0199	0.2726	0.00	0.45
5*g*. 3 ft. 6 in. below surface, . .	0.0295	0.0533	0.0116	0.2036	0.05	0.50

Series 6.

From Three-quarters of a Mile West of Boylston Centre on Wooded Hillside East of Muddy Brook. Samples taken from Surface to Three Feet below Surface. All Samples dried at 100° C.

	Loss on Ignition. (Per Cent.)	Carbon. (Per Cent.)	Nitrogen. (Per Cent.)	Ratio. $\frac{c}{n}$
6a. Surface to 2 in. below, ...	9.69	8.93	0.11	81.2
6b. 2 in. to 4 in. below surface, . . .	4.31	1.30	0.04	32.5
6c. 4 in. to 7 in. below surface, . . .	4.06	0.91	0.11	8.3
6d. 7 in. to 10 in. below surface, . . .	2.83	0.69	0.02	34.5
6e. 10 in. to 16 in. below surface, . . .	2.50	0.30	0.02	15.0
6f. 3 ft. below surface, ...	1.77	0.16	0.01	16.0

Sanitary Analysis of Water with which the Soils had been treated as described.

[Parts per 100,000.]

	Free Ammonia.	Free Ammonia after Standing One Week.	Albuminoid Ammonia.	Oxygen Consumed.	Color with Distilled Water.	Effect of Soils on Color of Cochituate Water of Color 0.55.
6a. Surface to 2 in. below, . .	0.0800	0.2921	0.4726	7.0009	0.60	1.00
6b. 2 in. to 4 in. below surface, .	0.0392	0.0574	0.0770	1.5740	0.30	0.70
6c. 4 in. to 7 in. below surface, .	0.0361	0.0323	0.0519	1.0977	0.38	0.60
6d. 7 in to 10 in. below surface, .	0.0209	0.0116	0.0243	0.3368	0.10	0.53
6e. 10 in to 16 in. below surface, .	0.0340	0.0142	0.0288	0.5060	0.20	0.55
6f. 3 ft. below surface, . . .	0.0142	0.0077	0.0110	0.1478	0.00	0.10

Series 7.

From Swamp at Head of Boylston Millpond, about Three-quarters of a Mile above Boylston Station. Samples taken from Surface to Three Feet Three Inches below Surface. All Samples dried at 100° C.

	Loss on Ignition. (Per Cent.)	Carbon. (Per Cent.)	Nitrogen. (Per Cent.)	Ratio. $\frac{c}{n}$
7a. Surface to 2 in. below, ...	22.31	12.53	0.96	13.0
7b. 2 in. to 4 in. below surface, . . .	24.59	13.05	0.54	24.2
7c. 4 in. to 8 in. below surface, . . .	17.12	8.75	0.86	10.2
7d. 8 in. to 12 in. below surface, . . .	9.14	3.96	0.21	18.9
7e. 12 in. to 21 in. below surface, . . .	3.93	1.44	0.09	16.0
7f. 21 in. to 39 in. below surface, . . .	1.98	0.51	0.04	12.8
7g. 39 in. below surface, ...	0.66	0.06	0.00	-

Sanitary Analysis of Water with which the Soils had been treated as described.

[Parts per 100,000.]

	Free Ammonia.	Free Ammonia after Standing One Week.	Albuminoid Ammonia.	Oxygen Consumed.	Color with Distilled Water.	Effect of Soils on Color of Cochituate Water of Color 0.55.
7a. Surface to 2 in. below, . .	0.1360	0.4000	0.4970	6.4000	0.40	0.70
7b. 2 in. to 4 in. below surface, .	0.1486	0.5429	0.4486	7.4286	0.50	0.90
7c. 4 in. to 8 in. below surface, .	0.1360	0.3440	0.4970	4.6000	0.12	0.55
7d. 8 in. to 12 in. below surface, .	0.0274	0.0709	0.0937	2.7429	0.50	1.00
7e. 12 in. to 21 in. below surface, .	0.0305	0.0267	0.0438	1.0857	0.30	0.70
7f. 21 in. to 39 in. below surface, .	0.0173	0.0220	0.0502	0.8471	0.10	0.55
7g. 39 in. below surface, . .	0.0179	0.0245	0.0080	0.1365	0.02	0.45

Series 8.

From Bottom of Oakdale Millpond from Depths of Three to Twelve Feet. All Samples dried at 100° C.

	Loss on Ignition. (Per Cent.)	Carbon. (Per Cent.)	Nitrogen. (Per Cent.)	Ratio. $\frac{c}{n}$
8a. Near head in 3 ft. of water,	0.91	0.07	0.01	7.0
8b. ¼ mile below head in 5 ft. of water,	0.11	0.06	0.00	–
8c. ½ mile below head in 7 ft. of water,	10.16	4.10	0.36	11.4
8d. ¾ mile from head in 9 feet of water,	10.45	4.17	0.35	11.9
8e. 500 ft. above W. & N. R.R. in 12 ft of water,	14.75	6.56	0.53	12.4
8f. 500 ft. below W. & N. R.R. in 12 ft. of water,	4.72	2.18	0.15	14.5

Sanitary Analysis of Water with which the Soils had been treated as described.

[Parts per 100,000.]

	Free Ammonia.	Free Ammonia after Standing One Week.	Albuminoid Ammonia.	Oxygen Consumed.	Color with Distilled Water.	Effect of Soils on Color of Cochituate Water of Color 0.55.
8a. Near head in 3 ft. of water,	0.0186	0.0121	0.0251	0.2224	0.01	0.55
8b. ¼ mile below head in 5 ft. of water.	0.0162	0.0027	0.0144	0.1854	0.00	0.60
8c. ½ mile below head in 7 ft. of water.	0.2100	0.2000	0.2042	3.1408	0.50	0.90
8d. ¾ mile from head in 9 ft. of water.	0.1707	0.2240	0.2227	3.8500	0.50	0.70
8e. 500 ft. above W. & N. R.R. in 12 ft. of water.	0.1943	0.2286	0.1838	2.7500	0.30	0.75
8f. 500 ft. below W. & N. R.R. in 12 ft. of water.	0.1103	0.0855	0.0790	1.3707	0.55	0.85

Series 9.

From Pasture Land about One and One-quarter Miles below West Boylston, on South Side of Railroad, which had never been cultivated. Samples taken from Surface to Twenty Inches below Surface. Samples dried at 100° C.

	Moisture. (Per Cent.)	Loss on Ignition. (Per Cent.)	Hydrogen. (Per Cent.)	Carbon. (Per Cent.)	Nitrogen. (Per Cent.)	Ratio. $\frac{c}{n}$
9*a*. Surface to 2 in. below, . .	31.13	19.89	1.45	11.92	0.66	18.06
9*b*. 2 in. to 4 in. below, . . .	29.17	11.52	0.66	5.32	0.48	11.08
9*c*. 4 in. to 7 in. below, . . .	26.17	8.37	0.62	3.56	0.26	13.69
9*d*. 7 in. to 10 in. below, . .	26.19	5.16	0.42	1.38	0.03	46.00
9*e*. 10 in. to 15 in. below, . .	22.55	3.16	0.31	0.87	0.06	14.50
9*f*. 15 in. to 20 in. below, . .	18.47	2.43	0.22	0.85	0.08	10.63

Sanitary Analysis of Water with which the Soils had been treated as described.

[Parts per 100,000.]

	Free Ammonia.		Albuminoid Ammonia.		Oxygen Consumed.		Color.	
	After 3 Days.	After 1 Week.	After 3 Days.	After 1 Week.	After 3 Days.	After 1 Week.	After 3 Days.	After 1 Week.
9*a*, ...	0.0096	0.0024	0.0530	0.1436	1.8330	2.1840	1.15	1.50
9*b*, ...	0.0056	0.0008	0.0254	0.0228	0.3003	0.4368	0.15	0.25
9*c*, ...	0.0040	0.0072	0.0188	0.0180	0.1170	0.1326	0.04	0.10
9*d*, ...	0.0016	0.0048	0.0066	0.0078	0.0429	0.0702	0.00	0.00
9*e*, ...	0.0096	0.0104	0.0066	0.0072	0,0156	0.0585	0.00	0.00
9*f*, ...	0.0048	0.0016	0.0050	0.0052	0.0195	0.0624	0.00	0.00

SERIES 10.

From Land recently cleared of Good-sized Timber and never cultivated, about Midway between Boylston and South Clinton, South Side of Valley. Samples taken from Surface to Two Feet Six Inches below. Dried at 100° C.

	Moisture. (Per Cent.)	Loss on Ignition. (Per Cent.)	Hydrogen. (Per Cent.)	Carbon. (Per Cent.)	Nitrogen. (Per Cent.)	Ratio. $\frac{c}{n}$
10a. Surface to 2 in. below, . .	62.87	26.65	1.92	18.07	0.94	19.22
10b. 2 in. to 4 in. below, . . .	54.26	19.63	1.15	10.47	0.58	18.02
10c. 4 in. to 7 in. below, . . .	44.23	11.12	0.63	5.66	0.32	17.69
10d. 7 in. to 12 in. below, . .	32.21	3.40	0.34	1.54	0.20	7.70
10e. 12 in. to 17 in. below, . .	29.57	2.85	0.28	0.85	0.31	2.74
10f. 2 ft. 6 in. below, . . .	17.60	0.52	0.05	0.04	0.11	0.36

Sanitary Analysis of Water with which the Soils had been treated as described.

[Parts per 100,000.]

	Free Ammonia.		Albuminoid Ammonia.		Oxygen Consumed.		Color.	
	After 3 Days.	After 1 Week.	After 3 Days.	After 1 Week.	After 3 Days.	After 1 Week.	After 3 Days.	After 1 Week.
10a, . . .	0.0560	0.0384	0.0902	0.1420	4.0560	6.3180	–	7.50
10b, . . .	0.0232	0.0224	0.0382	0.0320	0.8970	1.0257	0.80	4.50
10c, . . .	0.0064	0.0032	0.0264	0.0208	0.5144	0.6512	0.80	1.00
10d, . . .	0.0056	0.0024	0.0240	0.0254	0.2440	0.6448	0.30	1.20
10e, . . .	0.0056	0.0072	0.0738	0.0436	0.1584	1.3280	0.08	1.00
10f, . . .	0.0096	0.0024	0.0074	0.0066	0.0864	0.1008	0.03	0.12

Appendix No. 5.

CHEMICAL ANALYSES OF WATER FROM THE SOURCES INVESTIGATED.

In the following tabulations are given, first, the analysis of water from the larger surface water sources now used by the cities and towns in the metropolitan district, arranged alphabetically by towns; and, second, the analysis of water from other sources which have been investigated with a view to obtaining from them an additional supply of water for this district, arranged alphabetically by sources.

The State Board of Health began in June, 1887, to make analyses of water from many of the sources which it then thought might possibly be used in the not distant future for the supply of the metropolitan district. These examinations were made monthly, and were continued for two years. Since the Legislature authorized and directed the State Board of Health to make the investigation which is the subject of this report, many additional analyses have been made.

In order to present the results in a concise form, the average of analyses, made in the same calendar month of different years, is given in the tables, instead of the individual analyses, and is assumed to represent the character of the water at the portion of the year represented by that month. In most cases the tables contain an analysis of the water for each month in the year, and the average analysis given at the bottom of the table represents, in a fair way for purposes of comparison, the average character of the water during the whole year.*

The water from most of the new sources examined is not polluted to such an extent as to make the chemical analysis differ much from what it would be if such pollution did not exist, although the excess of chlorine over the normal amount, as given at the bottom of each table, may be regarded as an approximate measure of the amount of artificial pollution.

* The individual analyses, from 1887 to 1893 inclusive, may be found in the special report of the State Board of Health upon the Examination of Water Supplies, 1890 and the annual reports of the Board for the years 1890 to 1893 inclusive. Those made in 1894 will appear in the annual report of the Board for that year.

The analyses do, however, show clearly the amount of impurity in the water due to natural causes; and in comparing them for this purpose the determinations to be particularly noted are the color, the total albuminoid ammonia and the oxygen consumed.

In the case of water flowing in streams these natural impurities are derived mainly from the contact of the water with vegetable matter in swamps and very shallow ponds; and, of the three determinations, the color is the best one to use as an index of the amount of this impurity.

The color of water is expressed by numbers which increase with the amount of color. The standard used is nesslerized ammonia, as described on page 531 of the special report of the State Board of Health upon the Examination of Water Supplies, 1890, and on page 329 of the annual report for the year 1892. The average color of Boston water as drawn from a tap at the Massachusetts Institute of Technology during the year 1894 has been 0.69.

The odor is obtained by agitating the water which has stood for some time in a half-filled closed gallon bottle, and smelling the air in the bottle the moment the stopple is removed. It is obvious that a much stronger odor is obtained by this method than would be obtained from water in an open vessel which had not been agitated.

An opinion as to the relative quality of the water which the various sources will supply should not be based wholly upon the character of the water now flowing in the stream, because a storage reservoir built upon it may furnish a water of very different character. If the reservoir is carefully prepared for the reception of water by the removal of all soil and vegetable matter from its bottom and sides, and is deep, the water will improve by storage. If, on the other hand, the soil and vegetable matter are not removed, or the reservoir is very shallow, the water will deteriorate. A small reservoir in which the water is replaced frequently will cause less change in the character of the water than a large one; and a very large, well-cleaned and deep reservoir, in which the water is not replaced more frequently than once a year, will cause a very great improvement in the quality of the water by bleaching and the decomposition of dead organic matter, and by giving time for the death of disease germs which may find their way into the streams feeding it; moreover, by the drainage of swamps upon the water-shed the water can be prevented to a very large extent from taking up the organic matter which is represented in the analysis by the three determinations to which attention has already been called.

The analyses have all been made under the direction of Dr. Thomas M. Drown, chemist of the Board.

Boston Water Works.

Sudbury River Supply. — *Chemical Examination of Water from Reservoir No. 2, Framingham.*

[Parts per 100,000.]

Month.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Suspended.		Nitrates.	Nitrites.		
January, .	V. slight.	Slight.	1.07	5.13	2.13	.0011	.0236	.0205	.0031	.35	.0163	.0001	1.2111	1.7
February, .	Slight.	V. slight.	0.91	4.57	1.81	.0011	.0193	.0166	.0027	.29	.0174	.0000	.9614	1.3
March, .	Slight.	V. slight.	0.73	4.15	1.69	.0005	.0202	.0176	.0026	.27	.0116	.0001	.8448	1.3
April, .	V. slight.	Slight.	0.74	3.25	1.35	.0003	.0172	.0150	.0022	.23	.0083	.0001	.6884	0.9
May, . .	Slight.	Slight.	0.95	3.59	1.66	.0005	.0233	.0193	.0040	.28	.0073	.0001	.8353	1.0
June, .	Distinct.	Slight.	1.21	4.35	2.09	.0010	.0276	.0221	.0055	.24	.0073	.0001	1.3256	1.0
July, . .	Slight.	Slight.	1.04	4.37	2.10	.0010	.0304	.0255	.0049	.24	.0038	.0001	.8913	1.2
August, .	Distinct.	Slight.	0.83	4.36	1.77	.0010	.0297	.0244	.0053	.28	.0038	.0001	.6635	1.2
September,	Distinct.	Slight.	0.84	4.15	1.80	.0008	.0294	.0235	.0059	.27	.0033	.0001	.6896	1.3
October, .	Slight.	Cons.	1.02	4.74	2.15	.0007	.0290	.0252	.0038	.32	.0045	.0001	.6528	1.2
November,	Slight.	Slight.	1.00	4.26	1.54	.0011	.0266	.0226	.0040	.36	.0063	.0002	.7716	1.3
December,	Slight.	Slight.	1.01	5.03	2.08	.0010	.0251	.0223	.0028	.36	.0141	.0002	.9321	1.5
Average,	....	....	0.95	4.33	1.85	.0008	.0251	.0212	.0039	.29	.0087	.0001	.8723	1.2

This table is based upon analyses made monthly, from June, 1887, to November, 1894, inclusive. The samples were collected from the reservoir, near the gate-house, at a depth of eight feet beneath the surface. Excess of chlorine, 0.09. Odor, generally vegetable, occasionally mouldy or unpleasant, sometimes none; on heating, the odor is generally stronger.

Sudbury River Supply. — *Chemical Examination of Water from Reservoir No 3, Framingham.*

[Parts per 100,000.]

Month.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Suspended.		Nitrates.	Nitrites.		
January, .	Slight.	Slight.	0.87	5.93	2.03	.0032	.0247	.0220	.0027	.47	.0249	.0002	.9113	2.2
February, .	Slight.	Slight.	0.79	5.55	2.03	.0054	.0202	.0178	.0024	.41	.0360	.0002	.9091	1.8
March, .	Slight.	Slight.	0.69	4.92	1.69	.0071	.0203	.0175	.0028	.36	.0309	.0002	.8048	1.8
April, .	Distinct.	Slight.	0.59	4.12	1.58	.0039	.0191	.0159	.0032	.30	.0249	.0002	.6770	1.4
May, . .	Slight.	Cons.	0.74	4.13	1.63	.0007	.0225	.0185	.0040	.36	.0214	.0002	.7733	1.4
June, .	Distinct.	Slight.	0.97	4.94	2.00	.0023	.0280	.0230	.0050	.35	.0150	.0002	.9429	1.6
July, . .	Slight.	Slight.	0.90	5.13	2.15	.0025	.0307	.0264	.0043	.34	.0256	.0002	.9819	1.7
August, .	Slight.	Slight.	0.77	4.89	1.85	.0020	.0305	.0256	.0049	.39	.0056	.0002	.7796	1.9
September,	Slight.	Slight.	0.82	5.06	1.82	.0051	.0319	.0255	.0064	.41	.0043	.0002	.7175	2.0
October, .	Distinct.	Cons.	0.78	5.44	2.05	.0023	.0322	.0254	.0068	.42	.0065	.0001	.7384	1.8
November,	Slight.	Slight.	0.98	5.41	2.19	.0025	.0307	.0258	.0049	.48	.0108	.0002	.7587	1.8
December,	Slight.	Slight.	0.76	5.33	1.85	.0026	.0282	.0242	.0040	.51	.0213	.0002	.6435	2.0
Average,	....	....	0.81	5.07	1.91	.0033	.0266	.0223	.0043	.40	.0189	.0002	.8032	1.8

This table is based upon analyses made monthly, from June, 1887, to November, 1894, inclusive. The samples were collected from the reservoir, near the gate-house, at a depth of eight feet beneath the surface. Excess of chlorine, 0.19. Odor, vegetable, sometimes mouldy or unpleasant, and occasionally disagreeable.

COCHITUATE SUPPLY. — *Chemical Examination of Water from Lake Cochituate, in Wayland.*

[Parts per 100,000.]

MONTH.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Sus-pended.		Nitrates.	Nitrites.		
January, .	Slight.	Slight.	0.28	5.01	1.35	.0027	.0174	.0144	.0030	.46	.0162	.0002	.3246	2.1
February,	Slight.	Slight.	0.29	5.08	1.57	.0029	.0169	.0137	.0032	.45	.0229	.0001	.3868	2.0
March, .	Slight.	Slight.	0.34	4.96	1.39	.0017	.0180	.0151	.0029	.48	.0247	.0001	.5008	2.0
April, .	Slight.	Slight.	0.28	4.99	1.44	.0009	.0184	.0147	.0037	.46	.0221	.0002	.3199	1.8
May, . .	Slight.	Cons.	0.28	4.60	1.48	.0010	.0199	.0161	.0038	.45	.0206	.0002	.3879	1.9
June, .	Slight.	Slight.	0.23	4.49	1.44	.0022	.0184	.0145	.0039	.45	.0181	.0002	.4352	1.7
July, . .	Slight.	Slight.	0.16	4.41	1.50	.0014	.0193	.0158	.0035	.44	.0145	.0004	.4450	2.0
August, .	Slight.	V. slight.	0.14	4.74	1.34	.0010	.0185	.0152	.0033	.46	.0080	.0003	.3649	2.0
September,	Slight.	Slight.	0.11	4.58	1.29	.0007	.0198	.0158	.0040	.46	.0044	.0002	.3514	2.1
October, .	Slight.	Slight.	0.12	4.76	1.39	.0004	.0177	.0143	.0034	.47	.0076	.0001	.3553	2.0
November,	Slight.	Slight.	0.20	4.88	1.30	.0030	.0174	.0141	.0033	.48	.0106	.0002	.3476	2.1
December,	Slight.	Slight.	0.22	4.99	1.43	.0051	.0202	.0170	.0032	.47	.0141	.0004	.4017	2.3
Average,	....	....	0.22	4.79	1.41	.0019	.0185	.0151	.0034	.46	.0153	.0002	.3851	2.0

This table is based upon analyses made monthly, from June, 1887, to November, 1894, inclusive. The samples were collected in the gate-house. Excess of chlorine, 0.22. Odor, generally faintly vegetable, occasionally mouldy or disagreeable, sometimes none; during the last two years the odor has been stronger and frequently unpleasant.

MYSTIC SUPPLY. — *Chemical Examination of Water from Mystic Lake.*

[Parts per 100,000.]

MONTH.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Sus-pended.		Nitrates.	Nitrites.		
1894.														
January, .	Slight.	Slight.	0.04	15.85	1.80	.0480	.0180	.0164	.0016	3.02	.0760	.0012	.2168	5.1
February, .	None.	V. slight.	0.05	15.55	2.55	.0600	.0132	.0118	.0014	2.98	.1000	.0015	.2275	5.1
March, .	Slight, milky.	Slight.	0.08	13.90	2.15	.0736	.0292	.0214	.0078	2.43	.0870	.0015	.4048	5.0
April, .	Slight.	Slight.	0.12	12.65	1.95	.0776	.0208	.0164	.0044	2.42	.0730	.0008	.2364	4.6
May, . .	Slight.	Cons.	0.18	11.90	2.10	.0374	.0234	.0168	.0066	2.18	.0600	.0015	.3000	4.0
June, .	Distinct.	Cons., yellow gr'n.	0.15	12.85	2.65	.0320	.0280	.0174	.0106	2.49	.0650	.0008	.2964	4.2
July, . .	Distinct, green.	Slight, green.	0.05	12.90	2.30	.0062	.0206	.0160	.0046	2.82	.0580	.0010	.2618	4.2
August, .	Decided.	Cons., greenish brown.	0.12	14.25	2.00	.0010	.0394	.0216	.0178	2.80	.0150	.0012	.2695	5.8
September,	Slight.	Sli't, yellow br'n.	0.12	14.45	3.50	.0016	.0228	.0162	.0066	2.94	.0350	.0006	.2156	4.9
October, .	Distinct.	Cons.	0.12	16.90	2.50	.0018	.0240	.0172	.0068	4.21	.0300	.0009	.2251	5.0
November,	Decided.	Cons., eartby.	0.07	24.85	3.60	.0224	.0170	.0096	.0074	7.86	.0550	.0014	.2156	7.4
December,	Distinct.	Slight.	0.18	21.20	3.25	.0952	.0260	.0208	.0052	5.56	.0450	.0015	.2603	6.9
Average,	....	....	0.11	15.60	2.53	.0381	.0235	.0168	.0067	3.48	.0583	.0012	.2608	5.2

Owing to the change from time to time in the character of the water of Mystic Lake, it has been thought best to give the analyses for 1894, instead of the average for a series of years, in order to represent most nearly the present character of the water The samples were collected from the lake near the gate-house. The excess of chlorine, amounting to 3.14, is due in part to tannery wastes, and during the last three months of the year may also be due in part to the lowering of the lake below the level of tide water, so that it is not a correct measure of the amount of pollution by sewage. Odor, generally musty or disagreeable.

Cambridge Water Supply.

Chemical Examination of Water from Fresh Pond, Cambridge.

[Parts per 100,000.]

MONTH.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Albuminoid.				Nitrates.	Nitrites.		
							Total.	Dissolved.	Sus-pended.					
1894.														
January, .	Slight.	Con., gr'n.	0.25	7.35	1.90	.0114	.0172	.0152	.0020	.64	.0200	.0014	.4251	3.2
February, .	Slight.	Slight.	0.30	6.70	2.10	.0084	.0174	.0142	.0032	.65	.0150	.0005	.4600	3.0
March, .	Slight.	Slight.	0.35	6.80	1.85	.0004	.0208	.0182	.0026	.62	.0300	.0002	.4920	3.0
April, .	V. slight.	Con., gr'n & brown flocks.	0.32	6.65	1.80	.0000	.0198	.0164	.0034	.66	.0280	.0003	.4004	3.1
May, . .	Distinct.	Con., gr'n.	0.30	6.15	1.90	.0008	.0192	.0158	.0034	.64	.0200	.0002	.4520	2.7
June, .	Distinct.	Con., yellow gr'n.	0.30	6.15	1.85	.0010	.0228	.0194	.0034	.58	.0330	.0004	.4235	2.9
July, . .	Distinct, gr'n scum.	Sli't, gr'n.	0.28	6.65	1.85	.0064	.0270	.0198	.0072	.63	.0100	.0006	.4543	2.7
August, .	V. slight.	Sli't, gr'n.	0.23	6.65	1.90	.0016	.0188	.0166	.0022	.60	.0030	.0006	.3696	2.9
September,	Slight.	Sli't, gr'n.	0.18	8.50	1.50	.0002	.0202	.0150	.0052	.67	.0225	.0005	.3388	3.1
October, .	Slight, green.	Sli't, gr'n.	0.20	7.00	1.50	.0012	.0182	.0150	.0032	.74	.0100	.0003	.3357	3.1
November,	Slight.	Con., gr'n.	0.40	7.35	1.70	.0274	.0168	.0128	.0040	.78	.0150	.0008	.3542	3.6
December,	Slight.	Con., li'ht green.	0.50	7.75	1.85	.0164	.0204	.0154	.0050	.71	.0130	.0022	.3657	3.5
Average,	....	....	0.30	6.98	1.81	.0063	.0199	.0162	.0037	.66	.0183	.0007	.4059	3.1

The character of the water in Fresh Pond is changing from year to year with the increasing amount of Stony Brook water turned into it, so that, in order to represent most nearly the present character of the water the analyses for the year 1894 only are given, instead of the average for a series of years. The samples were collected from the pump well, at the pumping station. Odor, generally distinctly vegetable, becoming somewhat stronger and frequently unpleasant on heating.

Chemical Examination of Water from Stony Brook Storage Reservoir, Waltham.

[Parts per 100,000.]

MONTH.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Albuminoid.				Nitrates.	Nitrites.		
							Total.	Dissolved.	Sus-pended.					
January, .	V. slight.	V. slight.	0.68	5.63	1.94	.0019	.0209	.0188	.0021	.38	.0391	.0002	.6838	2.3
February, .	V. slight.	V. slight.	0.51	5.20	1.64	.0035	.0159	.0137	.0022	.37	.0413	.0001	.5847	2.2
March, .	Slight.	V. slight.	0.57	5.06	1.80	.0023	.0210	.0185	.0025	.36	.0233	.0001	.7028	2.0
April, .	Slight.	Slight.	0.60	4.53	1.67	.0009	.0227	.0195	.0032	.34	.0207	.0001	.6497	1.5
May, . .	Slight.	Slight.	0.77	4.83	1.82	.0011	.0229	.0204	.0025	.38	.0147	.0002	.7916	1.8
June, .	V. slight.	Slight.	1.05	5.56	2.28	.0025	.0322	.0277	.0045	.35	.0098	.0002	.8225	1.8
July, . .	Slight.	Slight.	0.76	5.45	2.12	.0018	.0291	.0233	.0058	.37	.0108	.0002	.6177	2.1
August, .	Distinct.	Slight.	0.75	5.37	1.86	.0018	.0287	.0247	.0040	.39	.0020	.0001	.4393	2.2
September,	Distinct.	Slight.	0.57	5.30	1.77	.0029	.0267	.0214	.0053	.40	.0066	.0001	.5183	2.1
October, .	Slight.	Slight.	0.75	5.64	1.96	.0041	.0281	.0242	.0039	.42	.0059	.0001	.4547	2.2
November,	Slight.	Cons.	0.76	5.64	2.81	.0029	.0242	.0206	.0036	.48	.0150	.0001	.5784	2.3
December,	Slight.	Slight.	0.72	5.86	2.09	.0016	.0234	.0193	.0041	.43	.0263	.0002	.5694	2.5
Average,	....	....	0.71	5.34	1.98	.0023	.0246	.0210	.0036	.39	.0180	.0001	.6177	2.1

This table is based upon analyses made monthly, from June, 1887, to November, 1894, inclusive. The samples were collected from the reservoir near the surface at the dam. Excess of chlorine, 0.11. Odor, generally vegetable, rarely mouldy or unpleasant, becoming somewhat stronger on heating.

Lynn Water Supply.

Chemical Examination of Water from Birch Pond, Lynn.

[Parts per 100,000.]

MONTH.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Sus-pended.		Nitrates.	Nitrites.		
January, .	Distinct.	Slight.	0.58	5.05	1.93	.0063	.0370	.0225	.0145	.64	.0085	.0001	.5427	1.4
February, .	Slight.	Slight.	0.64	4.50	1.70	.0207	.0295	.0229	.0066	.60	.0110	.0003	.5716	1.5
March, .	Slight.	Slight.	0.65	4.65	1.90	.0171	.0237	.0218	.0019	.63	.0070	.0001	.5064	1.4
April, .	Distinct.	Cons.	0.52	3.65	1.13	.0017	.0279	.0213	.0066	.49	.0040	.0002	.4726	0.7
May, . .	Slight.	Cons.	0.41	3.00	1.15	.0007	.0228	.0175	.0053	.42	.0015	.0001	.5321	0.7
June, .	Distinct.	Cons.	0.60	3.95	1.53	.0015	.0230	.0192	.0038	.51	.0015	.0001	.5042	0.7
July, . .	Distinct.	Slight.	0.48	4.00	1.80	.0008	.0291	.0214	.0077	.50	.0000	.0000	.5018	1.1
August, .	Slight.	Slight.	0.55	3.83	1.63	.0017	.0244	.0212	.0032	.51	.0000	.0000	.4769	0.8
September,	Distinct.	Cons.	0.70	3.90	1.45	.0018	.0301	.0214	.0087	.50	.0010	.0000	.5166	1.1
October, .	Slight.	Slight.	1.10	4.08	1.88	.0018	.0342	.0256	.0086	.52	.0050	.0001	.5960	0.8
November,	Slight.	Slight.	1.60	6.20	2.90	.0026	.0370	.0345	.0025	.60	.0225	.0003	.9990	1.5
December,	Distinct.	Cons.	1.00	4.53	1.80	.0043	.0391	.0293	.0098	.46	.0210	.0001	.7761	1.5
Average,	....	....	0.74	4.28	1.73	.0051	.0298	.0232	.0066	.53	.0069	.0001	.5830	1.1

These analyses represent the two years from December, 1892, to November, 1894, inclusive This reservoir has received its supply in recent years not only from its own water-shed but also from other reservoirs and streams from which the city of Lynn has authority to take water. The samples were collected from the reservoir, near the gate-house, one foot beneath the surface. Excess of chlorine, 0.09. Odor, generally vegetable, frequently mouldy or unpleasant; on heating, the odor is generally stronger and sometimes disagreeable.

Chemical Examination of Water from Breed's Pond, Lynn.

[Parts per 100,000.]

MONTH.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Sus-pended.		Nitrates.	Nitrites.		
January, .	Slight.	Slight.	0.88	4.63	1.75	.0027	.0273	.0218	.0055	.66	.0105	.0001	.6113	1.4
February, .	Slight.	Slight.	0.55	3.73	1.43	.0118	.0213	.0179	.0034	.59	.0060	.0003	.4599	1.2
March, .	Slight.	Slight.	0.55	3.53	1.33	.0064	.0163	.0143	.0020	.55	.0085	.0001	.5053	1.1
April, .	Slight.	Slight.	0.60	3.60	1.25	.0019	.0184	.0164	.0020	.53	.0060	.0003	.4972	0.7
May, . .	Slight.	Slight.	0.52	3.55	1.40	.0009	.0210	.0185	.0025	48	.0000	.0000	.5688	0.7
June, .	Distinct.	Cons.	0.62	3.75	1.58	.0015	.0188	.0155	.0033	.53	.0030	.0001	.5396	0.7
July, . .	Slight.	Slight.	0.50	3.40	1.33	.0005	.0218	.0192	.0026	.58	.0015	.0001	.5598	1.1
August, .	Distinct.	Slight.	0.57	3.38	1.23	.0008	.0235	.0181	.0054	.56	.0000	.0000	.4508	1.1
September,	Slight.	Slight.	0.65	3.38	1.35	.0007	.0219	.0188	.0031	.55	.0010	.0001	.4595	0.9
October, .	Slight.	Slight.	0.62	3.68	1.73	.0014	.0249	.0210	.0039	.52	.0025	.0001	.4572	0.9
November,	Slight.	Slight.	0.85	3.68	1.38	.0031	.0233	.0207	.0026	.62	.0050	.0002	.5517	0.7
December,	Distinct.	Cons.	0.80	3.78	1.55	.0039	.0249	.0203	.0046	.49	.0110	.0001	.5655	1.3
Average,	....	....	0.64	3.67	1.44	.0030	.0219	.0185	.0034	.56	.0046	.0001	.5189	1.0

These analyses represent the two years from December, 1892, to November, 1894, inclusive. The samples were collected from the pond, near the gate house, about one foot beneath the surface. Excess of chlorine, 0.12. Odor, generally distinctly vegetable and frequently unpleasant, becoming stronger on heating.

Chemical Examination of Water from the Saugus River at Howlett's Pond, Saugus.

[Parts per 100,000.]

MONTH.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Suspended.		Nitrates.	Nitrites.		
1894.														
February, .	V. slight.	Slight.	1.10	6.35	2.40	.0030	.0216	.0194	.0022	.59	.0050	.0002	.9600	2.9
March, .	Slight.	Slight.	0.80	5.05	2.30	.0006	.0228	.0202	.0026	.55	.0150	.0002	.8104	1.8
April, .	Slight.	Cons., yellowish.	0.60	5.80	2.20	.0008	.0196	.0162	.0034	.65	.0130	.0001	.5813	2.1
May, . .	Slight.	Cons.	1.80	6.80	3.05	.0018	.0324	.0298	.0026	.69	.0050	.0002	1.2972	2.3
June, .	Slight.	Slight.	1.50	6.85	3.35	.0014	.0308	.0290	.0018	.58	.0030	.0000	1.0865	2.2
July, . .	Slight.	Slight.	0.90	9.20	2.60	.0000	.0312	.0276	.0036	1.19	.0000	.0001	.7854	4.0
August, .	Slight.	Cons., brown.	1.10	11.75	4.90	.0348	.0316	.0284	.0032	1.80	.0300	.0100	.5837	4.7
September,	Slight.	Slight.	1.00	11.50	3.35	.0062	.0346	.0292	.0054	1.40	.0220	.0025	.5852	5.6
October, .	Slight.	Cons.	0.68	13.05	4.85	.0028	.0410	.0298	.0112	2.04	.0050	.0020	.6901	6.0
November,	V. slight.	Con., reddish b'wn	1.60	9.00	3.90	.0012	.0398	.0362	.0036	.76	.0030	.0001	1.7160	3.5
December,	V. slight.	V. slight.	1.70	10.15	4.05	.0090	.0356	.0330	.0026	1.04	.0220	.0003	1.3860	3.8
Average,	....	....	1.16	8.68	3.36	.0056	.0310	.0272	.0038	1.02	.0112	.0014	.9529	3.5

The analyses of samples from this source cover only the period from February to December, inclusive, 1894. The samples were collected from Howlett's Pond, at the place where water is diverted from the river for the water supply of the city of Lynn. Excess of chlorine, 0.70. Odor, generally decidedly vegetable and very frequently mouldy or unpleasant; on heating, the odor is sometimes disagreeable.

Assabet River.

Chemical Examination of Water from the Assabet River, below Northborough.

[Parts per 100,000.]

MONTH.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Suspended.		Nitrates.	Nitrites.		
January, .	V. slight.	V. slight.	0.30	3.20	0.85	.0006	.0142	.0122	.0020	.23	.0100	.0002	–	–
February, .	V. slight.	Cons.	0.50	4.43	1.53	.0040	.0279	.0209	.0070	.24	.0140	.0001	–	–
March, .	V. slight.	V. slight.	0.40	3.73	1.25	.0030	.0232	.0190	.0042	.23	.0075	.0002	–	–
April, .	Slight.	Slight.	0.55	3.43	1.40	.0011	.0319	.0297	.0022	.19	.0075	.0002	–	–
May, . .	Slight.	Slight.	1.20	4.50	1.90	.0019	.0300	.0279	.0021	.17	.0055	.0001	–	1.6
June, .	Slight.	Slight.	0.80	4.84	1.84	.0025	.0216	.0216	.0000	.20	.0115	.0003	–	–
July, . .	Slight.	V. slight.	0.50	4.69	1.31	.0038	.0235	.0214	.0021	.23	.0075	.0002	–	–
August, .	Slight.	Slight.	0.60	5.03	1.29	.0057	.0259	.0210	.0049	.28	.0060	.0002	–	–
September,	Slight.	Slight.	0.55	4.93	1.70	.0036	.0273	.0229	.0044	.28	.0065	.0001	–	–
October, .	Slight.	Slight.	0.98	4.88	1.53	.0016	.0267	.0256	.0011	.28	.0090	.0002	–	–
November,	Slight.	Slight.	0.75	4.88	1.33	.0009	.0225	.0203	.0022	.26	.0075	.0000	–	–
December,	Slight.	Slight.	0.68	4.13	1.38	.0029	.0189	.0151	.0038	.25	.0080	.0002	–	–
Average,	....	....	0.65	4.39	1.44	.0026	.0245	.0215	.0030	.24	.0084	.0002	–	–

This table is based upon analyses made monthly, from June, 1887, to May, 1889, inclusive. The samples were collected from the river, at Wood's Mill Pond, about one mile below the village of Northborough. Excess of chlorine, 0.07. Odor, faintly vegetable.

Assawompsett Pond.

Chemical Examination of Water from Assawompsett Pond, Lakeville.

[Parts per 100,000.]

Month.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Sus-pended.		Nitrates.	Nitrites.		
January,	Slight.	Sl't, white.	0.20	3.55	1.30	.0002	.0268	–	–	.46	.0050	.0000	–	–
March,	Slight.	Slight.	0.53	3.10	1.25	.0000	.0174	.0128	.0046	.48	.0040	.0000	.5460	0.6
May,	Slight.	Slight.	0.50	3.95	1.30	.0000	.0175	.0140	.0035	.44	.0020	.0001	.5655	0.8
June,	Slight.	Slight.	0.52	3.59	1.75	.0002	.0168	.0139	.0029	.47	.0017	.0000	.5392	0.4
July,	V. slight.	V. slight.	0.30	3.40	1.40	.0000	.0126	.0112	.0014	.53	.0000	.0000	.4273	0.8
August,	Slight.	Slight.	0.20	3.80	1.70	.0000	.0146	.0132	.0014	.51	.0030	.0000	.3542	0.6
September,	Slight.	Slight.	0.14	3.15	1.08	.0007	.0170	.0138	.0032	.53	.0025	.0000	.3752	0.5
October,	Slight.	Sl't, white.	0.15	3.25	1.20	.0000	.0168	.0146	.0022	.58	.0030	.0000	.3041	0.8
November,	Slight.	Slight.	0.25	2.95	1.10	.0006	.0164	.0132	.0032	.51	.0030	.0000	.3936	0.6
December,	Slight.	Slight.	0.06	2.72	1.02	.0002	.0161	.0125	.0036	.49	.0027	.0000	.3590	0.4
Average,	....	....	0.28	3.35	1.31	.0002	.0162*	.0133	.0030	.50	.0027	.0000	.4293	0.6

This table is based upon analyses of seventeen samples, collected in the years 1887, 1888, 1891, 1893 and 1894. The samples were collected from the pond, at various points. Excess of chlorine, 0.05. Odor, generally faintly vegetable, occasionally mouldy, sometimes none.

* January omitted in making the average.

Charles River.

Chemical Examination of Water from the Charles River at South Natick.

[Parts per 100,000.]

Month.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Sus-pended.		Nitrates.	Nitrites.		
January,	V. slight.	V. slight.	0.75	4.27	1.67	.0005	.0186	.0167	.0019	.33	.0107	.0002	.7450	1.4
February,	Slight.	Slight.	0.58	4.39	1.41	.0017	.0213	.0194	.0019	.33	.0118	.0002	.7640	1.3
March,	Slight.	Slight.	0.67	4.15	1.62	.0004	.0223	.0194	.0029	.32	.0140	.0001	.7984	1.3
April,	V. slight.	Slight.	0.92	3.82	1.73	.0007	.0249	.0224	.0025	.30	.0037	.0002	.9376	0.9
May,	Slight.	Slight.	1.23	4.38	1.93	.0019	.0309	.0278	.0031	.34	.0033	.0001	.7426	1.3
June,	V. slight.	Slight.	1.55	4.91	2.23	.0024	.0365	.0325	.0040	.27	.0037	.0001	1.2074	1.3
July,	V. slight.	V. slight.	0.65	4.28	1.75	.0008	.0262	.0233	.0029	.34	.0024	.0002	.7084	1.8
August,	V. slight.	V. slight.	0.78	5.04	1.78	.0007	.0226	.0199	.0027	.41	.0043	.0000	.5834	1.1
September,	Slight.	Slight.	0.63	5.26	1.80	.0007	.0278	.0259	.0019	.44	.0033	.0001	.5424	1.6
October,	V. slight.	V. slight.	0.81	5.24	1.84	.0006	.0235	.0195	.0040	.49	.0058	.0000	.4899	1.5
November,	Slight.	Slight.	0.95	5.45	2.25	.0005	.0262	.0228	.0034	.53	.0068	.0001	.9533	1.8
December,	V. slight.	V. slight.	0.75	4.85	1.88	.0010	.0198	.0176	.0022	.39	.0110	.0001	.8932	1.1
Average,	....	....	0.86	4.67	1.82	.0010	.0251	.0223	.0028	.37	.0067	.0001	.7806	1.4

This table is based upon analyses made monthly, from June, 1887, to May, 1889, inclusive, two analyses made in July, 1890, and analyses made monthly from August, 1893, to November, 1894, inclusive. The samples were collected from the river, just above the dam at South Natick. Excess of chlorine, 0.16. Odor, generally distinctly vegetable, frequently mouldy, rarely disagreeable.

Deerfield River.

Chemical Examination of Water from the Deerfield River at Shelburne Falls.

[Parts per 100,000.]

MONTH.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Sus-pended.		Nitrates.	Nitrites.		
January,	None.	V. slight.	0.15	3.35	0.95	.0000	.0058	.0046	.0012	.08	.0150	.0000	.2270	1.4
March,	Distinct.	Slight.	0.10	3.50	1.00	.0000	.0074	.0062	.0012	.11	.0090	.0000	.2520	1.6
May,	Slight.	Slight.	0.48	3.25	1.45	.0006	.0154	.0140	.0014	.11	.0000	.0000	.5453	1.7
June,	None.	V. slight.	0.45	4.05	1.25	.0000	.0142	.0126	.0016	.13	.0030	.0000	.4173	1.7
July,	V. slight.	Slight.	0.30	3.60	0.65	.0006	.0132	.0118	.0014	.16	.0000	.0000	.3480	2.0
August,	V. slight.	Slight.	0.50	3.70	0.95	.0004	.0158	.0142	.0016	.13	.0000	.0000	.4697	1.4
September,	Slight.	Slight.	0.56	3.78	1.40	.0006	.0116	.0103	.0013	.14	.0025	.0000	.5618	1.6
October,	None.	V. slight.	0.50	3.20	9.35	.0000	.0112	.0090	.0022	.10	.0000	.0000	.5913	1.6
November,	V. slight.	Slight.	0.65	3.40	1.20	.0000	.0108	.0084	.0024	.11	.0030	.0000	.6583	1.4
December,	Distinct.	Heavy.	0.35	2.90	1.50	.0006	.0180	.0116	.0064	.06	.0100	.0001	.5796	0.5
Average,	....	....	0.40	3.47	1.17	.0003	.0123	.0103	.0020	.11	.0042	.0000	.4650	1.5

This table is based upon analyses of eleven samples, collected from September, 1893, to November, 1894, inclusive. The samples were collected from the river, about a mile above the bridge in the village of Shelburne Falls. Excess of chlorine, 0.03. Odor, faintly vegetable or none, becoming somewhat stronger on heating.

Ipswich River.

Chemical Examination of Water from the Ipswich River, near Howe's Station, between Danvers and Middleton.

[Parts per 100,000.]

MONTHS.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Hardness.
							Albuminoid.						
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Sus-pended.		Nitrates.	Nitrites.	
1892.													
January,	V. slight.	Slight.	1.20	6.55	3.10	.0000	.0194	.0180	.0014	.49	.0100	.0001	1.6
February,	V. slight.	Slight.	1.00	6.35	2.35	.0006	.0204	.0180	.0024	.51	.0120	.0001	1.7
March,	V. slight.	V. slight.	1.20	5.90	2.00	.0000	.0226	.0176	.0050	.38	.0070	.0000	1.1
April,	V. slight.	V. slight.	1.10	4.50	2.20	.0000	.0248	.0236	.0012	.39	.0070	.0000	1.3
May,	Slight.	Slight.	1.30	4.85	1.85	.0028	.0370	.0342	.0028	.34	.0100	.0000	1.3
June,	Slight	Slight.	1.60	6.20	2.55	.0006	.0278	.0252	.0026	.43	.0000	.0000	1.3
July,	V. slight.	V. slight.	1.70	5.90	3.10	.0006	.0334	.0282	.0042	.40	.0000	.0000	1.6
August,	V. slight.	V. slight.	0.55	4.75	1.55	.0022	.0190	.0162	.0028	.67	.0090	.0000	2.0
September,	V. slight.	Slight.	1.40	7.55	2.95	.0006	.0370	.0290	.0080	.58	.0100	.0000	1.9
October,	V. slight.	Slight.	0.90	6.75	2.50	.0006	.0262	.0230	.0032	.57	.0090	.0001	2.1
November,	V. slight.	V. slight.	2.50	8.10	4.65	.0000	.0440	.0370	.0070	.48	.0070	.0001	2.6
December,	V. slight.	V. slight.	1.90	7.05	3.50	.0012	.0326	.0290	.0036	.43	.0180	.0001	2.5
Average,	....	....	1.36	6.20	2.69	.0008	.0287	.0250	.0037	.47	.0082	.0000	1.7

These analyses were made monthly during the year 1892. The samples were collected from the river, at the bridge, near Howe's station. Excess of chlorine, 0.16. Odor, vegetable and grassy, or sweetish, rarely mouldy.

Merrimack River.

Chemical Examination of Water from the Merrimack River above Lowell, opposite the Intake of the Lowell Water Works.

[Parts per 100,000.]

Month.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Sus-pended.		Nitrates.	Nitrites.		
January, .	V. slight.	Slight.	0.35	3.60	1.20	.0037	.0131	.0108	.0023	.21	.0075	.0001	.4353	1.3
February, .	Slight.	Slight.	0.35	3.63	1.40	.0023	.0173	.0137	.0036	.15	.0105	.0001	.4650	1.5
March, .	Slight.	Cons.	0.45	3.10	1.13	.0016	.0159	.0128	.0031	.16	.0150	.0000	.5153	0.7
April, .	Slight.	Cons.	0.42	2.63	0.95	.0007	.0135	.0107	.0028	.15	.0040	.0001	.4397	0.7
May, . .	Distinct.	Cons.	0.50	3.18	1.18	.0030	.0121	.0097	.0024	.12	.0070	.0002	.4997	0.9
June, .	Slight.	Slight.	0.32	3.18	1.13	.0024	.0154	.0103	.0051	.16	.0050	.0001	.3842	1.1
July, . .	Slight.	Slight.	0.20	4.50	1.28	.0030	.0147	.0119	.0028	.22	.0050	.0003	.3103	1.1
August, .	Slight.	Slight.	0.19	3.45	1.10	.0018	.0129	.0095	.0034	.20	.0040	.0002	.2931	1.1
September,	Slight.	Slight.	0.29	3.58	1.15	.0049	.0142	.0124	.0018	.19	.0055	.0001	.3426	1.2
October, .	Slight.	Slight.	0.25	3.43	1.38	.0046	.0126	.0103	.0023	.18	.0055	.0000	.3776	1.4
November,	Slight.	Slight.	0.38	3.85	1.30	.0033	.0133	.0107	.0026	.18	.0150	.0000	.5124	1.7
December,	Slight.	Slight.	0.43	3.50	1.43	.0033	.0158	.0144	.0014	.18	.0095	.0001	.5648	1.4
Average,	....	....	0.34	3.47	1.22	.0029	.0142	.0114	.0028	.18	.0078	.0001	.4283	1.2

The amount of polluting matter turned into this river is increasing from year to year, and, in order to show the character of the water at a recent period, the average of analyses for the two years from November, 1892, to October, 1894, inclusive, is used, instead of the average of all of the analyses that have been made. The samples were collected from the river, about one foot beneath the surface. Excess of chlorine, 0.08. Odor, distinctly vegetable and musty, becoming somewhat stronger on heating.

Chemical Examination of Water from the Merrimack River above Lawrence opposite the Intake of the Lawrence Water Works.

[Parts per 100,000.]

Month.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Sus-pended.		Nitrates.	Nitrites.		
January, .	Slight.	Slight.	0.38	4.18	1.58	.0058	.0157	.0135	.0022	.26	.0080	.0003	.4973	1.3
February, .	Slight.	Slight.	0.38	3.85	1.50	.0038	.0193	.0158	.0035	.22	.0135	.0001	.4796	1.3
March, .	Distinct.	Cons.	0.50	2.93	1.10	.0030	.0204	.0155	.0049	.14	.0095	.0001	.5588	0.7
April, .	Slight.	Slight.	0.44	3.25	1.30	.0014	.0157	.0115	.0042	.15	.0050	.0001	.4733	0.7
May, . .	Distinct.	Cons.	0.52	3.05	1.13	.0027	.0163	.0140	.0023	.16	.0115	.0002	.5132	1.9
June, .	Distinct.	Cons.	0.41	3.73	1.33	.0079	.0187	.0157	.0030	.19	.0040	.0002	.4515	1.2
July, . .	Slight.	Slight.	0.21	3.50	1.33	.0103	.0184	.0146	.0038	.25	.0035	.0003	.3874	1.4
August, .	Slight.	Slight.	0.23	4.05	1.48	.0102	.0171	.0126	.0045	.29	.0045	.0002	.3648	1.1
September,	Slight.	Slight.	0.28	4.08	1.53	.0098	.0163	.0134	.0029	.24	.0060	.0001	.3340	1.3
October, .	Slight.	Slight.	0.62	4.65	1.88	.0087	.0175	.0144	.0031	.23	.0035	.0003	.6659	1.4
November,	Distinct.	Cons.	0.48	4.10	1.40	.0025	.0159	.0135	.0024	.21	.0120	.0003	.5586	1.7
December,	Slight.	Slight.	0.44	4.03	1.43	.0030	.0191	.0155	.0036	.20	.0125	.0002	.5994	1.1
Average,	....	....	0.41	3.78	1.42	.0058	.0175	.0142	.0033	.21	.0078	.0002	.4920	1.3

The amount of polluting matter turned into this river is increasing from year to year, and, in order to show the character of the water at a recent period, the average of analyses for the two years from November, 1892, to October, 1894, inclusive, is used, instead of the average of all of the analyses that have been made. The samples were collected from the river, opposite the intake of the Lawrence Water Works, about one foot beneath the surface. Excess of chlorine, 0.08. Odor, distinctly vegetable and musty.

Nashua River.

Chemical Examination of Water from the South Branch of the Nashua River at Clinton.

[Parts per 100,000.]

MONTH.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Sus-pended.		Nitrates.	Nitrites.		
January, .	Slight.	Slight.	0.32	3.50	1.12	.0014	.0177	.0147	.0030	.18	.0113	.0001	.5499	0.9
February, .	Slight.	Slight.	0.33	3.43	0.98	.0012	.0143	.0120	.0023	.23	.0097	.0001	.4029	1.3
March, .	Slight.	Slight.	0.27	3.53	0.82	.0009	.0127	.0095	.0032	.19	.0090	.0001	.5080	0.6
April, .	Slight.	Slight.	0.32	2.80	0.98	.0002	.0132	.0110	.0022	.17	.0050	.0001	.4335	0.6
May, . .	Slight.	Slight.	0.50	3.30	1.28	.0009	.0175	.0131	.0044	.15	.0043	.0001	.5440	0.9
June, .	V. slight.	Slight.	0.42	3.89	0.97	.0021	.0155	.0116	.0039	.18	.0063	.0001	.6622	0.8
July, . .	Slight.	Slight.	0.62	3.89	1.27	.0014	.0227	.0179	.0048	.20	.0060	.0001	.3634	0.9
August, .	Slight.	Slight.	0.43	3.73	1.13	.0011	.0181	.0147	.0034	.24	.0043	.0001	.3378	1.0
September,	V. slight.	Slight.	0.29	4.08	1.30	.0016	.0171	.0128	.0043	.26	.0045	.0001	.2873	1.6
October, .	Slight.	Slight.	0.36	3.98	1.34	.0009	.0209	.0148	.0061	.25	.0057	.0001	.2321	1.5
November,	Slight.	Slight.	0.54	4.15	1.53	.0007	.0155	.0122	.0033	.30	.0078	.0002	.5019	1.7
December,	Slight.	Slight.	0.38	3.52	1.15	.0006	.0163	.0143	.0020	.21	.0050	.0001	.6474	0.9
Average,	....	....	0.40	3.65	1.16	.0011	.0168	.0132	.0036	.21	.0066	.0001	.4559	1.1

This table is based upon analyses made monthly, from June, 1887, to May, 1889, inclusive, two analyses made in October, 1891, and analyses made monthly from August, 1893, to November, 1894, inclusive. The samples were collected from the river, above the dam of the Lancaster Mills Company. Excess of chlorine, 0.07. Odor, vegetable, occasionally mouldy.

Quinepoxet River.

Chemical Examination of Water from the Quinepoxet River, a tributary of the Nashua River, in Holden.

[Parts per 100,000.]

MONTH.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Sus-pended.		Nitrates.	Nitrites.		
January, .	Slight.	Slight.	0.65	3.48	1.18	.0003	.0131	.0115	.0016	.20	.0090	.0000	.6809	0.5
February, .	Decided.	Cons.	0.47	3.23	1.00	.0006	.0118	.0094	.0024	.21	.0110	.0000	.5293	0.9
March, .	Distinct.	Cons.	0.52	3.03	1.30	.0002	.0148	.0104	.0044	.17	.0075	.0000	.6024	0.5
April, .	Slight.	Cons.	0.48	2.58	1.23	.0000	.0165	.0116	.0049	.21	.0040	.0001	.4658	0.7
May, . .	Slight.	Cons.	0.70	3.20	1.68	.0000	.0209	.0182	.0027	.17	.0015	.0001	.7280	0.4
June, .	Slight.	Slight.	0.63	3.83	1.53	.0023	.0238	.0195	.0043	.18	.0025	.0001	.6391	0.7
July, . .	Slight.	Slight.	0.60	4.05	1.53	.0136	.0229	.0176	.0053	.28	.0025	.0001	.5844	1.0
August, .	Slight.	Cons.	0.64	3.78	1.82	.0043	.0217	.0183	.0034	.26	.0067	.0001	.5124	1.4
September,	V. slight.	Slight.	0.53	4.02	1.52	.0014	.0247	.0208	.0039	.28	.0053	.0002	.4184	0.8
October, .	Slight.	Slight.	0.48	3.97	1.38	.0041	.0207	.0157	.0050	.27	.0053	.0001	.4037	0.8
November,	V. slight.	Slight.	0.65	4.80	1.85	.0016	.0265	.0218	.0047	.36	.0033	.0002	.9147	1.0
December,	Slight.	Slight.	0.85	3.95	1.73	.0002	.0193	.0160	.0033	.24	.0080	.0000	.8229	0.9
Average,	....	....	0.60	3.66	1.48	.0024	.0197	.0159	.0038	.24	.0056	.0001	.6084	0.8

This table is based upon analyses made monthly, during the year 1892, and from August, 1893, to November, 1894, inclusive. The samples were collected from the river, at a highway bridge, about one mile above the line between Sterling and West Boylston. Excess of chlorine, 0.11. Odor, generally faintly vegetable, rarely mouldy or unpleasant; on heating, the odor becomes somewhat stronger and frequently mouldy.

Stillwater River.

Chemical Examination of Water from the Stillwater River, a tributary of the Nashua River in Sterling.

[Parts per 100,000]

Month.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Sus-pended.		Nitrates.	Nitrites.		
January, .	None.	V. slight.	0.52	3.00	1.08	.0003	.0094	.0082	.0012	.17	.0055	.0000	.5288	0.7
February, .	V. slight.	V. slight.	0.35	3.23	1.00	.0002	.0087	.0072	.0015	.17	.0075	.0000	.4226	0.8
March, .	V. slight.	V. slight.	0.42	2.88	0.90	.0000	.0103	.0078	.0025	.13	.0090	.0000	.4320	0.7
April, .	V. slight.	Cons.	0.35	2.80	1.13	.0005	.0108	.0096	.0012	.14	.0040	.0000	.3873	0.6
May, . .	V. slight.	Slight.	0.68	3.20	1.33	.0008	.0180	.0136	.0044	.12	.0010	.0000	.6120	0.5
June, .	Slight.	Slight.	0.48	3.35	1.38	.0005	.0163	.0130	.0033	.14	.0025	.0000	.4620	1.0
July, . .	V. slight.	Slight.	0.43	3.30	1.08	.0013	.0146	.0138	.0008	.14	.0025	.0000	.5621	1.3
August, .	V. slight.	Slight	0.41	3.35	1.25	.0003	.0157	.0130	.0027	.14	.0033	.0000	.3712	0.9
September,	V. slight.	Slight.	0.43	3.63	1.33	.0004	.0139	.0121	.0018	.12	.0043	.0001	.3764	0.8
October, .	V. slight.	Slight.	0.23	3.25	1.02	.0005	.0140	.0121	.0019	.17	.0043	.0000	.2830	0.8
November,	V. slight.	Slight.	0.77	4.18	1.53	.0013	.0203	.0173	.0030	.25	.0033	.0001	.5942	1.1
December,	V. slight.	V. slight.	0.54	3.30	1.35	.0000	.0117	.0101	.0016	.16	.0035	.0001	.6357	0.7
Average,	....	....	0.47	3.29	1.20	.0005	.0137	.0115	.0022	.15	.0042	.0000	.4723	0.8

This table is based upon analyses made monthly, during the year 1892, and from August, 1893, to November, 1894, inclusive. The samples were collected from the river, at a highway bridge, about one mile above the line between Sterling and West Boylston. Excess of chlorine, 0.01. Odor, vegetable, occasionally mouldy, sometimes none.

Shawsheen River.

Chemical Examination of Water from the Shawsheen River at Wilmington.

[Parts per 100,000.]

Month.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Sus-pended.		Nitrates.	Nitrites.		
January, .	None.	V. slight.	0.40	4.48	1.25	.0016	.0146	.0128	.0018	.31	.0205	.0002	–	–
February, .	V. slight.	Slight.	0.55	4.75	1.60	.0022	.0234	.0208	.0026	.36	.0225	.0002	–	–
March, .	Slight.	V. slight.	0.85	4.38	1.50	.0015	.0228	.0205	.0023	.43	.0075	.0002	–	–
April, .	V. slight.	Slight.	1.00	4.20	1.58	.0001	.0268	.0230	.0058	.36	.0070	.0002	–	–
May, . .	Slight.	Slight.	1.57	5.47	2.33	.0049	.0299	.0272	.0027	.28	.0067	.0001	.7738	1.6
June, .	V. slight.	Slight.	1.17	5.19	1.84	.0018	.0295	.0268	.0027	.32	.0053	.0001	1.6170	1.4
July, . .	V. slight.	Slight.	0.72	4.98	1.38	.0019	.0259	.0202	.0057	.34	.0007	.0000	.4420	1.6
August, .	V. slight.	V. slight.	1.03	5.75	2.07	.0008	.0304	.0292	.0012	.36	.0027	.0001	.4350	1.5
September,	V. slight.	V. slight.	0.35	5.58	2.00	.0008	.0176	.0162	.0014	.39	.0017	.0001	.2002	1.7
October, .	V. slight.	Slight.	0.98	5.52	1.90	.0005	.0235	.0219	.0016	.43	.0023	.0001	.2251	1.7
November,	V. slight.	Slight.	1.18	6.80	2.69	.0012	.0325	.0283	.0042	.47	.0038	.0001	.9476	2.2
December,	Slight.	Slight.	0.85	4.60	1.50	.0003	.0213	.0162	.0051	.27	.0150	.0002	.8123	2.2
Average,	....	....	0.89	5.14	1.80	.0015	.0249	.0219	.0030	.36	.0080	.0001	.6816	1.8

This table is based upon analyses made monthly, from June, 1887, to May, 1889, inclusive, one analysis made in November, 1893, and analyses made monthly, from May to November, inclusive, 1894. The samples were collected from the river at the point where it is crossed by the old Middlesex canal, between the towns of Wilmington and Billerica. Excess of chlorine, 0.11. Odor, generally faintly vegetable, rarely mouldy; on heating, the odor is generally somewhat stronger.

SWIFT RIVER.

Chemical Examination of Water from the East Branch of the Swift River in Greenwich.

[Parts per 100,000.]

MONTH.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Sus-pended.		Nitrates.	Nitrites.		
1894.														
April, .	V. slight.	Cons.	0.58	2.55	1.20	.0022	.0172	.0136	.0036	.14	.0000	.0000	.5648	0.3
October, .	V. slight.	Slight.	0.35	3.65	1.00	.0000	.0120	.0098	.0022	.15	.0030	.0000	.3773	1.3
Average,	....	....	0.47	3.10	1.10	.0011	.0146	.0117	.0029	.15	.0015	.0000	.4711	0.8

The samples were collected from the east branch of the Swift River, just above its confluence with the middle branch. Excess of chlorine, 0.05. Odor, faintly vegetable.

Chemical Examination of Water from the Middle Branch of the Swift River in Greenwich.

[Parts per 100,000.]

MONTH.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Sus-pended.		Nitrates.	Nitrites.		
1894.														
April, .	V. slight.	Slight.	0.43	2.65	1.10	.0024	.0124	.0106	.0018	.14	.0000	.0000	.4424	0.5
October, .	Slight.	Slight.	0.32	3.65	0.95	.0000	.0106	.0088	.0018	.11	.0000	.0000	.3349	1.3
Average,	....	....	0.38	3.15	1.03	.0012	.0115	.0097	.0018	.13	.0000	.0000	.3887	0.9

The samples were collected from the middle branch of the Swift River, just above its confluence with the east branch. Excess of chlorine, 0.03. Odor, faintly vegetable.

Chemical Examination of Water from the West Branch of the Swift River in Enfield.

[Parts per 100,000.]

Month.	Appearance.			Residue on Evaporation.		Ammonia.					Nitrogen as			
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Suspended.	Chlorine.	Nitrates.	Nitrites.	Oxygen Consumed.	Hardness.
1894.														
April,	V. slight.	Slight.	0.20	1.85	0.70	.0026	.0108	.0100	.0008	.16	.0000	.0000	.3065	0.2
December,	Slight.	Heavy, gray.	0.23	3.10	1.05	.0008	.0108	.0064	.0044	.12	.0070	.0000	.2772	0.8
Average,	....	....	0.22	2.48	0.88	.0017	.0108	.0082	.0026	.14	.0035	.0000	.2919	0.5

The samples were collected from the west branch of the Swift River at a road crossing the river about half a mile above its confluence with the main stream. Excess of chlorine, 0.04. Odor, very faintly vegetable.

Ware River.

Chemical Examination of Water from Ware River, at Cold Brook Station, Barre.

[Parts per 100,000.]

Month.	Appearance.			Residue on Evaporation.		Ammonia.					Nitrogen as			
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Suspended.	Chlorine.	Nitrates.	Nitrites.	Oxygen Consumed.	Hardness.
January,	Slight.	Slight.	0.73	3.90	1.55	.0004	.0166	.0148	.0018	.17	.0030	.0000	.7215	0.6
February,	Slight.	Slight.	0.60	3.50	1.50	.0016	.0116	.0096	.0020	.18	.0070	.0000	.5783	0.8
March,	V. slight.	Slight.	0.75	3.55	1.25	.0006	.0166	.0122	.0044	.14	.0030	.0000	.6760	0.8
April,	V. slight.	Slight.	0.70	2.90	1.30	.0004	.0132	.0112	.0020	.13	.0030	.0000	.5505	0.2
May,	Slight.	Slight.	0.95	2.90	1.75	.0000	.0184	.0168	.0016	.13	.0000	.0000	.8520	0.2
June,	Slight.	Slight.	1.30	3.70	1.70	.0010	.0246	.0226	.0020	.08	.0050	.0000	.9471	0.3
July,	V. slight.	Slight.	0.85	3.60	1.45	.0008	.0190	.0172	.0018	.10	.0000	.0000	.5644	0.8
August,	Slight.	Slight.	0.70	3.30	1.68	.0000	.0203	.0176	.0027	.12	.0000	.0000	.5938	1.0
September,	Slight.	Slight.	0.63	3.25	1.25	.0006	.0222	.0164	.0058	.14	.0000	.0001	.4004	0.9
October,	Slight.	Slight.	0.45	3.15	1.05	.0000	.0170	.0152	.0018	.15	.0000	.0000	.4180	0.6
November,	V. slight.	Slight.	0.73	3.88	1.67	.0005	.0180	.0148	.0032	.19	.0000	.0000	.7899	1.0
December,	V. slight.	Slight.	0.65	3.70	1.35	.0000	.0152	.0126	.0026	.17	.0000	.0000	.6513	0.9
Average,	....	....	0.75	3.44	1.46	.0005	.0177	.0151	.0026	.14	.0018	.0000	.6453	0.7

This table is based upon analyses of fifteen samples collected from August, 1893, to November, 1894, inclusive. The samples were collected from the river, at the railroad bridge near Cold Brook station, in the southeasterly part of the town of Barre. Excess of chlorine, 0.03. Odor, generally distinctly vegetable, rarely mouldy or unpleasant.

Lake Winnipiseogee, New Hampshire.

Chemical Examination of Water from Lake Winnipiseogee, N. H.

[Parts per 100,000.]

MONTH.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Albuminoid. Total.	Albuminoid. Dissolved.	Albuminoid. Suspended.		Nitrates.	Nitrites.		
January,	V. slight.	V. slight.	0.03	1.98	0.53	.0001	.0074	.0058	.0016	.11	.0045	.0000	–	–
February,	V. slight.	V. slight.	0.00	2.15	0.58	.0005	.0093	.0083	.0010	.12	.0055	.0000	–	–
March,	V. slight.	V. slight.	0.02	2.03	0.58	.0016	.0108	.0097	.0011	.12	.0055	.0001	–	–
April,	Slight.	Slight.	0.00	2.03	0.53	.0000	.0096	.0083	.0013	.12	.0040	.0000	–	–
May,	V. slight	V. slight.	0.02	2.10	0.58	.0000	.0088	.0075	.0013	.11	.0015	.0000	–	1.3
June,	Slight.	Slight.	0.00	2.34	0.77	.0001	.0083	.0079	.0013	.13	.0040	.0000	–	–
July,	None.	None.	0.00	2.10	0.55	.0001	.0091	.0077	.0014	.12	.0010	.0000	–	–
August,	V. slight.	V. slight.	0.00	2.26	0.51	.0006	.0088	.0072	.0016	.13	.0025	.0000	–	–
September,	V. slight.	V. slight.	0.00	2.19	0.63	.0000	.0092	.0075	.0017	.13	.0065	.0000	–	–
October,	V. slight.	V. slight.	0.03	2.05	0.53	.0000	.0099	.0095	.0004	.09	.0030	.0000	–	–
November,	Slight.	Slight.	0.00	1.98	0.63	.0000	.0093	.0087	.0006	.10	.0045	.0000	–	–
December,	V. slight.	Slight.	0.00	1.88	0.40	.0000	.0106	.0077	.0029	.12	.0035	.0000	–	–
Average,	....	....	0.01	2.09	0.57	.0002	.0093	.0079	.0014	.12	.0038	.0000	–	–

This table is based upon analyses made monthly, from June, 1887, to June, 1889, inclusive. The samples were collected at the Lake Company's dam at Lakeport, N. H. Excess of chlorine, 0.02. Odor, generally none, rarely vegetable.

Appendix No. 6.

WATER SUPPLY OF DIFFERENT QUALITIES FOR DIFFERENT PURPOSES.

By Dexter Brackett, C.E.

At times during a number of years the water from the Sudbury River and Lake Cochituate has been subject to offensive tastes and odors, and at all times it has more or less color, which renders it somewhat objectionable for table use. For this reason a large quantity of spring water has been sold in Boston, showing that many people are willing to pay an increased price for drinking water which is pure, colorless and palatable.

Surface water supplies where the water is received from a swampy territory, or where it is stored in artificial reservoirs from which the soil has not been removed, generally furnish a water of high color that is subject to tastes and odors which may not be detrimental to health, but are certainly objectionable to the senses.

The water from springs or wells is, on the other hand, in almost all cases colorless and free from objectionable tastes and odors; the temperature of the water is lower in summer than that of the surface waters; and when obtained from a source which is not contaminated by sewage, a supply of ground water is much preferable to a supply from a river or pond.

Taking into consideration the great expense of removing all the soil from storage reservoirs or of constructing works for the filtration of the entire supply of the metropolitan district, the question naturally arises as to the practicability of some division of the supply, either by supplying a spring or ground water for drinking and cooking purposes, or by furnishing an inferior water which would not be suitable for drinking or cooking, but which would be suitable for mechanical, manufacturing and other uses.

The question will then be considered under these two heads: —

First. — A supply of spring or ground water for drinking and culinary purposes.

Second. — A supply of water of inferior quality, not suitable for drinking or cooking, for mechanical, manufacturing and other purposes.

A Supply of Spring or Ground Water for Drinking and Culinary Purposes.

The cities of Newton and Waltham and the town of Brookline now have supplies of ground water of excellent quality, which are obtained from the gravelly soil in the valley of the Charles River. Some other towns in the metropolitan district now have supplies of ground water, but the quality of water is inferior to that furnished by the three places just mentioned.

By combining and developing the supplies of Newton, Waltham and Brookline, a daily supply of at least 12,000,000 gallons of excellent water can probably be obtained; but it is evident that this quantity would be but a very small proportion of the total amount required for the metropolitan district for all purposes, and that, in order to utilize these works to supply water for drinking and cooking purposes to the whole district, a separate system of works would be required.

The quantity of water actually required for drinking and culinary purposes is probably not more than three gallons daily per person; and if the water were to be delivered by the jug or barrel, as the spring water now is, a much smaller quantity would suffice; but in any public system of supply, where the water is distributed by pipes and can be had by opening a faucet, the quantity used would be much larger, and the unavoidable leakage from the 1,600 miles of mains and the 150,000 house services required for distribution of the water would also be a very considerable amount, even if the greatest care were used in laying them.

Considering these facts, it appears to me that six gallons daily per inhabitant is the minimum quantity which should be estimated upon as a supply for drinking and cooking purposes, and this quantity will not be sufficient unless very stringent regulations are adopted to prevent the unnecessary use and waste of water.

All the water should be supplied through meters, and the number and size of the faucets should be restricted, so that the opportunities for extravagant use and waste may be as few as possible.

On this basis of six gallons per capita, the 12,000,000 gallons which the works of Newton, Waltham and Brookline can be expected to furnish will be sufficient for the needs of the whole metropolitan district until about the year 1920. It will then be necessary to obtain an additional quantity, and, although no careful study has been made, a general knowledge of the available sources indicates that a limited supply may possibly be obtained in the upper portion of the Charles River valley, but that the most feasible source would be among the numerous ponds in the sandy soil in the vicinity of Plymouth.

As before indicated, the utilization of the Newton, Waltham and Brookline supplies for furnishing a supply of ground water to the entire metropolitan district will necessitate a distinct system of works, with pumping

stations, reservoirs and an entirely distinct system of pipe distribution. No surveys have been made for such a system, but in order to furnish an idea of the cost of this system of supply the following approximate estimate has been made, based upon the general cost of obtaining ground-water supplies, with a pipe distribution system of the same length as that now in use, but of much smaller sizes.

As the introduction of a duplicate supply will necessitate additional plumbing in all houses, entailing additional expense to every water taker, the cost of this work should be considered in the estimate. It appears to me that $40 per service is a fair allowance for the cost of this house plumbing, and this amount has been included in the following estimate : —

Works for collecting 12,000,000 gallons per day,	$1,200,000
Pumping stations and engines,	300,000
Reservoirs,	100,000
Force mains,	300,000
75,000 feet of twenty-four-inch pipe, at $4,	300,000
25,000 feet of twenty-inch pipe, at $3.20,	80,000
116,000 feet of sixteen-inch pipe, at $2.40,	278,400
95,000 feet of twelve-inch pipe, at $1.75,	166,250
175,000 feet of ten-inch pipe, at $1.50,	262,500
235,000 feet of eight-inch pipe, at $1.20,	282,000
1,500,000 feet of six-inch pipe, at $1,	1,500,000
6,400,000 feet of four-inch pipe, at $0.70,	4,480,000
150,000 service pipes from mains to buildings at $10,	1,500,000
150,000 meters, at $10,	1,500,000
House plumbing, 150,000 services, at $40,	6,000,000
	$18,249,150
Add ten per cent., for contingencies,	1,824,915
	$20,074,065

Taking into consideration the cost of maintenance, including the depreciation of the 150,000 meters, the total yearly cost of maintenance has been estimated at $400,000, to which must be added the interest and sinking fund requirements on the cost of the works, which can be estimated at four and one-half per cent., or $903,332.92, making the yearly cost of a supply of ground or spring water for drinking and cooking purposes $1,303,332.92, or $1.30 for each inhabitant.

A Supply of Water not Suitable for Drinking or Cooking, for Mechanical, Manufacturing and Other Purposes.

There are many purposes for which the public water supply is now used for which a water of quality inferior to that required for drinking and cooking would be equally good. This statement applies not only to the

supply for mechanical and manufacturing purposes, but also to that part of the domestic supply which is not used for drinking or cooking; but if the inferior water were introduced into houses, it would be very difficult if not impossible to so regulate the supply as to prevent its use for drinking purposes, with the consequent danger from typhoid fever and other kindred diseases caused by polluted drinking water.

This difficulty is well illustrated by the experience of the city of Lawrence, as stated in the annual report of the State Board of Health for the year 1893 (page 559). As there stated, the city of Lawrence is now furnished with a supply of filtered water, but in some of the factories a supply of unfiltered water from the canals is distributed to the sinks for washing purposes; and, although notices have been posted to warn the employees against drinking the canal water, nine deaths from typhoid fever occurred among the mill operatives from October, 1893, to May, 1894, and in every case they had drunk the unfiltered canal water. The total number of deaths in the city from this disease during the same time was seventeen.

While it would not be advisable to use water of an inferior quality in places where there would be danger of its being used for drinking, there are many places where its use would be attended with little if any danger to the health of the community.

For the supply of steam boilers, railroads and elevators, for street sprinkling and for many manufacturing purposes, an inferior water not suitable for drinking or cooking would be equally good.

If Mystic Lake should be abandoned as a source of water supply for drinking and cooking, as has been suggested by both the Boston Water Board and the State Board of Health, it can be utilized at a comparatively small expense to supply water of the inferior quality for the purposes above mentioned.

The railroads, sugar refineries and many of the large manufacturing establishments of the metropolitan district are so located that they can be supplied by a very short system of pipe distribution.

The accompanying plan shows a proposed system of distribution from the Mystic Works, which is designed to reach many of the largest consumers of water for mechanical and manufacturing purposes in Somerville, Cambridge, Charlestown, South Boston and Boston proper. It is estimated that the consumers on these lines of pipe now use between 5,000,000 and 6,000,000 gallons of water per day for purposes for which the inferior water might be substituted.

Under present conditions of operation, the safe capacity of the Mystic Works in a dry year is about 7,000,000 gallons per day; but a supply of 10,000,000 or 12,000,000 gallons can be obtained in most years, and when necessary the takers from these works could be supplied from the other sources, the distribution systems being connected.


MEDFORD
MALDEN
W Medford
Medford P.O.
MYSTIC DISTRIBUTING
RESERVOIR
SOMERVILLE
EVERETT
CHELSEA
Powder Horn Hill
CAMBRIDGE
30 in.
24 in.
20 in.
CHARLES RIVER
MYSTIC RIVER
Corey Hill
SCALE OF MILES.

At seasons of the year when there is a surplus of water in the other sources of supply, and until the consumption of the district reaches the capacity of the present works, it may not be advisable to use the Mystic supply, as there will be an additional cost for pumping.

The estimated cost of the mains is as follows: —

From the Mystic distributing reservoir through Somerville and Charlestown, across the Charles River bridge and around the water front to Congress Street, 35,000 feet of thirty-inch pipe at $5.50, .	$192,500
Through the city of Cambridge, across Essex Street bridge, through Commonwealth Avenue, Massachusetts Avenue, Albany Street, Lehigh Street, South Street, Kneeland Street, Federal Street and Atlantic Avenue to Congress Street, 42,400 feet of twenty-four-inch pipe, at $4, ...	169,600
Across Congress Street bridge, through Congress and A streets to Dorchester Avenue, 6,200 feet of twenty-inch pipe at $3.25, . .	20,150
Through Huntington Avenue, Boylston, Eliot and Kneeland streets, 9,000 feet of twenty-inch pipe, at $3.25, ...	29,250
Through Charles, Leverett, Minot, Lowell, Lancaster, Merrimack, Travers and Charlestown streets, 10,400 feet of twenty-inch pipe at $3.25, ...	33,800
Siphons and bridge crossings, ...	75,000
	$520,300
Add ten per cent., for contingencies, ...	52,030
	$572,330

Appendix No. 7.

SANITARY EXAMINATION OF NASHUA RIVER WATER-SHED.

The tables which follow contain the results of an inspection of the mills and villages upon the Nashua River water-shed, made by Mr. Chester W. Smith. The mills which will be flooded by the proposed reservoir are not included in the tables. A summary of the results of the inspection is given below.

Summary.

Kind of Mill or Factory.	Number of Mills or Factories.	Operatives Employed.
Woolen,	7	550
Cotton,	3	110
Wood-working,	16	108
Shoddy,	6	30
Tannery,	1	15
Emery wheel,	1	15
Pottery,	1	12
Grist and cider,	3	7
Total,	38	847

Number of villages in water-shed having a population of more than 100,	10
Population in villages,	4,446
Population in villages, exclusive of those living within limits of proposed reservoir,	2,979

Statistics of Mills and Factories on Nashua River Water-shed.

	TOWN.	Stream.	Description of Mill or Factory.	Power Used.	Horse-power of Steam.	Head and Fall in Feet.	Size and Kind of Water Wheel.	Number of Hands employed.	Character and Amount of Material used per Year, as far as known.	Disposal of Human Wastes.	Disposal of Manufacturing Wastes.	Character of Manufacturing Wastes.	
1	West Boylston,	Malden Brook,	Goodale's excelsior mill,	Water,	–	18	18″ Tyler scroll,	2	– – – – –	Privies,	Taken away,	Sawdust and shavings,	1
2	West Boylston,	Quinepoxet River,	Harris cotton mill,	Water and steam,	50	16	Holyoke turbine,	90	Raw cotton,	Privies over stream,	– –	No waste,	2
3	West Boylston,	Quinepoxet River,	Whiting cotton mill,	Water and steam,	85	20	96″ Hunt horizontal wheel,		Raw cotton,	Privies over stream,	– –	No waste,	3
4	West Boylston,	Quinepoxet River,	Benson's shoddy mill,	Water,	–	12	48″ Turbine,	5	300 tons of rags,	Privy over stream,	Burned,	Sweepings and some waste rags,	4
5	West Boylston,	Quinepoxet River,	Warfield's cotton yarn mill,	Water,	–	19	48″ Turbine,	20	Raw cotton,	Privies,	– –	No waste,	5
6	West Boylston,	Stillwater River,	Howe's saw mill,	Steam,	35	–	– –	25	1,200,000 feet of logs,	Privies,	Taken away,	Sawdust and shavings,	6
7	Holden,	Quinepoxet River,	Glen woollen mill,	Water and steam,	50	17	Two 30″ Hunt turbines,	35	Shoddy and cotton warp,	Privies over stream,	Into stream,	1,100 gallons daily of spent speck dye stuff and wash water,	7
8	Holden,	Quinepoxet River,	Canada shoddy mill,	Water and steam,	30	10	36″ Turbine,	3	300 tons of rags,	Privies,	Burned,	Sweepings and some waste rags,	8
9	Holden,	Branch of Quinepoxet River,	Farmer's saw and shoddy mill,	Water,	–	27	30″ Whitney turbine,	2	1,000,000 feet of timber,	Privies,	Principally burned,	Sawdust,	9
10	Holden,	Branch of Quinepoxet River,	Howe's shoddy mill,	Water,	–	14	60″ Leffel turbine,	3	225 tons of rags,	Privies,	Into stream,	22 tons of waste rags and sweepings annually,	10
11	Holden,	Branch of Quinepoxet River,	Bryant's cider, grist and planing mill,	Steam,	10	–	– –	2	Product 1,200 barrels of cider,	Privies,	Into stream,	Pomace and shavings,	11
12	Holden,	Branch of Quinepoxet River,	Chaffinville shoddy mill,	Water,	–	15*	Two 15″ Hercules turbines,	2	150 tons of rags,	Privy over stream,	Burned,	Sweepings and some waste rags,	12
13	Holden,	Branch of Quinepoxet River,	Dawson's woollen mill,	Steam,	100	–	– –	65	Wool, 65 tons of woollen shoddy, 15,000 pounds of logwood.	Privies over stream,	Into stream,	Discharge annually the refuse from 15,000 pounds of logwood and 500 pounds of aniline dyes, besides considerable soda-ash and soap	13
14	Holden,	Asnebumskit Brook,	Lovellville woollen mill,	Water and steam,	50	24 18 14	21″ Turbine, 21″ Turbine, 30″ Turbine,	50	Cotton warp and rags,	Privies over stream,	Into stream,	1,000 gallons daily of spent dye stuff and wash water,	14
15	Holden,	Asnebumskit Brook,	Day's shoddy mill,	Water and steam,	25	23†	21″ Turbine,	15	900 tons of rags,	Privies,	Burned,	Sweepings and some waste rags,	15
16	Holden,	Branch of Asnebumskit Brook,	Warren's tannery,	Steam,	50	–	– –	15	10,000 hides,	Privies,	Into stream,	4,000 gallons daily of spent tanning liquor, containing lime, etc.,	16
17	Holden,	Asnebumskit Brook,	Jefferson woollen mill (lower),	Water and steam,	150	9 13	33″ Hercules turbine, 30″ Hercules turbine,	150	Product 300,000 yards of ⅞ cloth, wool and woollen shoddy.	Closets into stream,	Into stream,	Discharge daily 3 pailfuls of soda-ash and 1 pailful of soap, also considerable quantities of refuse from logwood and aniline dyes.	17
18	Holden,	Asnebumskit Brook,	Jefferson woollen mill (upper),	Water and steam,	150	26	27″ Hercules turbine,	100	Woollen shoddy, cotton warp and wool. Product 900,000 yards of ⅞ cloth.	Closets into stream,	Into stream,	Considerable quantities of waste from speck dyeing and fulling,	18
19	Holden,	Quinepoxet River,	Quinepoxet woollen mill,	Water and steam,	100	25	27″ Turbine,	100	Cotton warp and woollen rags,	Closets into stream,	Into stream,	3,000 gallons daily of spent dye stuff and wash water,	19
20	Holden,	Quinepoxet River,	North Woods woollen mill,	Water and steam,	40	19	21″ Holyoke turbine,	50	Wool and woollen shoddy,	Closets into stream,	Into stream,	One barrel of waste logwood and aniline dye stuff, also three pailfuls of soap, discharged daily.	20
21	Holden,	Branch of Quinepoxet River,	Austin's saw mill,	Water,	–	24	15″ Orange turbine,	3	100,000 feet of timber,	Privies,	Burned,	Sawdust,	21
22	Holden,	Branch of Quinepoxet River,	Austin's moulding mill,	Water and steam,	15	19	14″ Orange horizontal wheel,		– – – – –	Privies,	Burned,	Sawdust and shavings,	22
23	Paxton,	Asnebumskit Brook,	Harrington's saw mill,	Water,	–	22	20″ Houston turbine,	6	350,000 feet of timber,	Privies,	Into stream,	Sawdust,	23
24	Paxton,	Asnebumskit Brook,	Harrington's box shop,	Water,	–	28	9″ Hercules turbine,		200,000 feet of boards,	Privies,	Burned,	Sawdust and shavings,	24
25	Sterling,	Waushacum Brook,	Sterling basket factory,	Water and steam,	28	8	40″ Leffel turbine,	6	100,000 feet of oak timber,	Privy over stream,	Burned,	Sawdust and shavings,	25
26	Sterling,	Waushacum Brook,	Waushacum pottery,	Steam,	10	–	– –	12	– – – – –	Privies,	Dumped near by,	Broken ware and ashes,	26
27	Sterling,	Stillwater River,	Sterling emery wheel factory,	Water and steam,	8	11	Two 18″ Orange turbines,	15	310,000 pounds of emery,	Privy over stream,	– –	No waste,	27
28	Sterling,	Stillwater River,	Allen's grist and cider mill,	Water,	–	13	36″ Blake turbine, 36″ Clark turbine,	3	18,000 bushels of apples, 12 carloads of grain.	Privies,	Principally taken away,	Pomace,	28
29	Sterling,	Justice Brook,	Washington saw and grist mill,	Water,	–	11	Two 36″ turbines,	2	1,000 bushels of grain, 175,000 feet of timber.	Privies,	Partly into stream,	Sawdust,	29
30	Princeton,	Branch of South Wachusett Brook,	Bigelow's saw and grist mill,	Steam,	45	..	– –	9	30 car loads of grain, 700,000 feet of timber.	Privies,	Burned or taken away,	Sawdust,	30
31	Princeton,	East Wachusett Brook,	Buck's chair shop,	Water and steam,	15	24*	15″ Hercules turbine,	20	1,200 cords of timber,	Privy over stream,	Principally burned,	Sawdust and shavings,	31
32	Princeton,	East Wachusett Brook,	Parker's turning and grist mill,	Water,	–	23	22″ Leffel turbine,	4	200 cords of timber,	Privy over stream,	Into stream,	Sawdust and shavings,	32
33	Princeton,	East Wachusett Brook,	Buck's saw mill,	Water,	–	14	44″ Leffel turbine,	2	1,200 cords of timber,	Privies,	Principally taken away,	Sawdust,	33
34	Princeton,	Keyes' Brook,	Keyes' toy shop, ‡	Water,	–	10	– –	6	– – –	– –	– –	– – – –	34
35	Princeton,	Keyes' Brook,	Temple's saw mill and chair shop,	Water and steam,	25	17	30″ Tyler turbine, 24″ Tyler turbine, 24″ Whitney turbine,	12	300,000 feet of timber,	Privy over stream,	Into stream,	Sawdust and shavings,	35
36	Princeton,	Keyes' Brook,	Stewart's chair shop,	Water,	–	16	30″ National turbine,	9	200,000 feet of lumber,	Privy over stream,	Burned,	Sawdust and shavings,	36
37	Leominster,	Justice Brook,	Bartlett's chair shop,	Water,	–	8	24″ Leffel turbine,	4	Product 10,000 chairs,	Privies,	Into stream,	Sawdust and shavings,	37
38	Leominster,	Justice Brook,	Bartlett's saw mill,	Water,	–	15	24″ Tyler turbine, 30″ Whitney turbine,		100,000 feet of timber,	Privies,	Into stream,	Sawdust and shavings,	38

* Raceway receives water from bottom of dam; 10 feet more head could be utilized.

† Raceway receives water from bottom of dam; 20 feet more head could be utilized.

‡ Not run at present; owner dead.

2 2

STATISTICS OF VILLAGES ON NASHUA RIVER WATER-SHED.

NAME.	Number of Houses.	Number of People.	Occupation.	Nationality.	Water Supply.	Disposal of Human Wastes.	Remarks.
Jefferson,	73	500	Woolen mill operatives.	French Canadian, Irish and American.	Wells,	Privies.	
Holden,	86	400	Farmers and tanners,	American,	One-third by pipe from spring, balance wells.	Privies.	
East Princeton,	31	120	Farmers and chair-shop employees.	American,	One-half by pipe from spring, balance wells.	Privies.	
Princeton,	50	200	Farmers,	American,	Wells,	Privies,	For three months in summer the population is increased to 500.
Sterling Centre,	90	550	Farmers,	American,	Wells,	Privies,	The natural drainage of ninety per cent. of village is toward a branch of the Stillwater River, and of ten per cent. toward Wekepeke Brook.
Sterling Camp Ground,	155	-*	- -	American,	Public wells,	Privies,	For three months in summer population is 550 and for one week it is increased to 3,000.
Oakdale,	141	1,256	Cotton mill operatives.	French Canadian and American.	Wells,	Privies,	Forty per cent. of village, including all of poorer portion, obliterated by proposed reservoir.
West Boylston,	127	732	Cotton mill operatives.	French Canadian, American and Irish.	Wells,	Privies,	Sixty-five per cent. of village obliterated by proposed reservoir.
Boylston Common,	95	398	Farmers,	American,	Wells,	Privies,	Fifteen per cent. of village obliterated by proposed reservoir.
Boylston Centre,	20	110	Farmers,	American,	Wells,	Privies.	
Boylston,	19	180	Cotton mill operatives.	French Canadian, English, Irish and American.	Eighty per cent. from Nashua River, balance wells.	Privies and cesspool near river.	Entire village obliterated by proposed reservoir.

* No permanent population.

INDEX.